SCIENTIFIC IDEAS OF TO-DAY

POPULARLY EXPLAINED

CHARLES R. GIBSON

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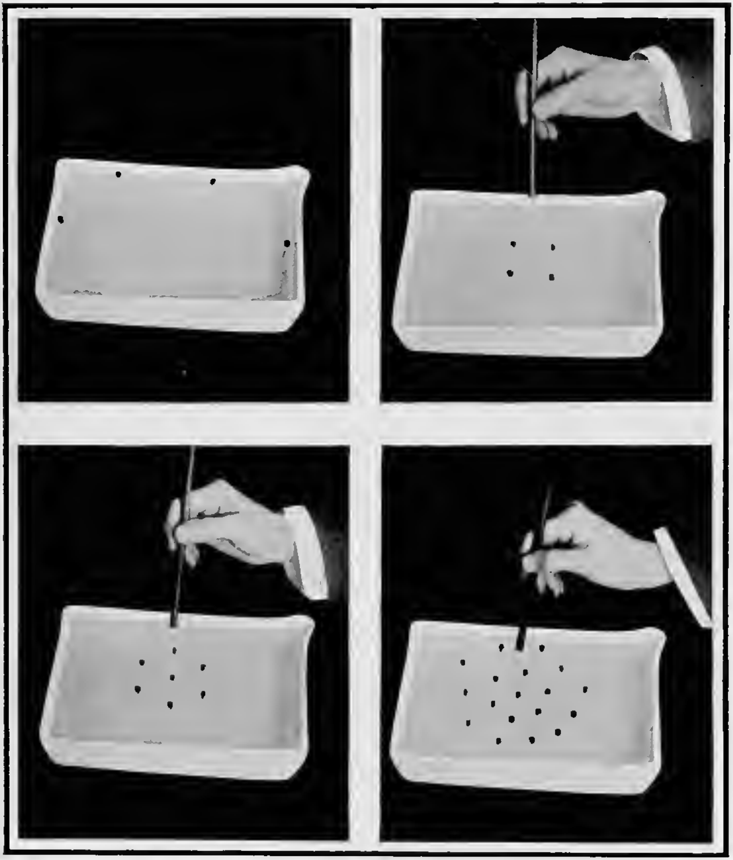

Regular Figures produced by Floating Magnets

In the first photograph the little upright magnetic needles may be seen projecting downwards from the small corks. Left alone, the similar poles repel one another, but in the other photographs the hand holds the opposite pole of a magnet above the centre of the basin, whereupon the little magnets invariably form definite figures according to their number. These experiments enable us to form a mental picture of the construction of the atom.

SCIENTIFIC IDEAS OF TO-DAY

A POPULAR ACCOUNT OF THE NATURE OF MATTER, ELECTRICITY, LIGHT, HEAT, &c. &c.

IN NON-TECHNICAL LANGUAGE

By

CHARLES R. GIBSON

Author of "Electricity of To-Day," "The Romance of Modern Electricity," "The Romance of Modern Photography," *&c. &c.*

With Forty-two Illustrations and Diagrams

LONDON

SEELEY AND CO. LIMITED

38 Great Russell Street

1909

PREFACE

THE more man's knowledge increases, the more do his text-books of science become necessarily complex and technical. To-day, few persons whose walk in life lies in other directions have either the time or the inclination to study technical treatises. And yet our scientific ideas of to-day are so very different from those of the preceding generation that many are desirous of understanding them. There is no reason why so many people should spend a lifetime upon this planet and know nothing or little of the forces by means of which the Creator formed the world, and maintains it in its present condition. Such questions as, What are the atoms of matter made of? What is light? What is electricity? and so on, are surely of interest to the tenants of this planet.

In the present volume the author has endeavoured to explain the scientific ideas of to-day without using language beyond the reach of any reader. His explanations demand no previous knowledge of science whatever, and no acquaintance with mathematics. The *Warning*, which is appended to this preface, has been suggested by incidents which have occurred in connection with some of the author's former books. From

questions put to him it has been evident, and indeed the questioners have acknowledged the fact, that they read the chapters irrespective of the order in which they were placed in the books.

The author is indebted to Professor James Muir, D.Sc., M.A., and Professor Magnus Maclean, M.A., D.Sc., F.R.S.E., of the Glasgow and West of Scotland Technical College, and to H. Stanley Allen, M.A., B.Sc., Senior Lecturer in Physics at King's College, University of London, for very kindly reading the proof-sheets. The author is also indebted to the following gentlemen in connection with the illustrations:—Professor James Muir, Dr. R. M. Buchanan, Walter A. Scoble, Charles Stewart, John M'Lennan, Glasgow; Professor E. E. Barnard, U.S.A.; Edgar Senior, Edward Chesterton, Rebman, Ltd. (*Archives of the Roentgen Ray*), Arthur E. Smith, London; also to Andrew A. Muir, Glasgow, for very kindly drawing the diagrams which appear in the text.

A WARNING

On picking up a book many readers are inclined to glance through the *Contents*, select a chapter which appears interesting from its title, and read that chapter first. Needless to say, this is a very bad plan, and especially so if the reader has no previous knowledge of the subject; for in each chapter the author presumes that the preceding chapters have been read. His aim is to make the whole text perfectly intelligible to every reader; but it would be quite impossible to make each chapter complete in itself without a wearying repetition of facts. By commencing at Chapter I. the whole subject becomes very simple as one goes along, each chapter leading on to the following one, like easy stepping-stones across a wide river.

Contents

Contents

Contents

LIST OF ILLUSTRATIONS

List of Illustrations and Diagrams

DIAGRAMS IN THE TEXT

SCIENTIFIC IDEAS OF TO-DAY

CHAPTER I

INTRODUCTION

The professor and the student—The meaning of a theory—A mistaken theory—Testing a theory—Laws of Nature

To make any scientific subject of real interest to the general reader one must presume that the reader has no previous knowledge whatever of the subject.

A learned friend has remarked to me that he used to admire the way in which a professor, now deceased, was wont to give his fellow-men credit for knowing far more than they did know. I admitted that this, no doubt, was a very generous frame of mind, but I maintained that it was far from being of assistance to the struggling student. My friend told me that he could remember one occasion, very many years ago, when he was in this great man's class. The professor put a question to a raw country student, and it was quite apparent to the class that the student knew no more of the

subject than did the desk in front of him. Nothing could have persuaded the learned professor of the student's complete ignorance. The question was put in another form, and yet in another and another, till at last it only demanded yes or no as an answer, and indeed it was clear which answer was wanted. When the student answered correctly, the learned professor almost lost his temper. "Man! I knew you knew it! Why do you make me drag it out of you bit by bit?"

My object in relating the foregoing incident is to emphasise the fact that if one desires to treat a subject "popularly," one must not presume any previous knowledge of the subject on the part of his readers. I trust, therefore, that any reader coming across statements of facts with which he is well acquainted, will bear with me, for the sake of those to whom such statements may be of service.

It will be well to remember that all our present knowledge has been gradually built up by man himself. Man found himself upon this planet, left to find out for himself the meaning of all that lay around him. Our present object is not to trace how civilised man came to make use of the forces of nature, but to consider the ideas he formed concerning things, and in particular the scientific ideas of our own day. In other words, we are to deal with theory rather than practice.

One sometimes finds people who consider theory to be a very useless sort of thing—a sort of wild

guess without which we should be none the poorer. It must be clear that a theory is more than a mere speculation. If I suggest that the moon is made of green cheese, my speculation is not entitled to be called a theory. I cannot bring forward any observed facts to support my suggestion.

When the ancients observed the sun rising in the east and setting in the west they very naturally suggested that the sun was making a continual journey round and round the earth. This theory accounted for the rising and setting of the sun; but when the motions of the planets were carefully observed, at a later date, it was found that the old Ptolemaic theory could not satisfactorily explain these planetary motions. But until the middle of the sixteenth century man believed his habitation to be securely fixed in space, while the sun, moon, and stars all moved around him.

We have seen that the original theory was found to be wrong, although it appeared at first to be founded on observed facts. The mistake was that all the facts had not been taken into account.

No doubt most of us have been deceived completely, at some time or other, as to whether we ourselves or some other observed body was in motion. The first sensation of going up in a balloon, on a quiet day, is that the earth is falling away from the balloon. A more common experience is that of a train moving very quietly out of a railway station in which another train is at rest. A

subject than did the desk in front of him. Nothing could have persuaded the learned professor of the student's complete ignorance. The question was put in another form, and yet in another and another, till at last it only demanded yes or no as an answer, and indeed it was clear which answer was wanted. When the student answered correctly, the learned professor almost lost his temper. "Man! I knew you knew it! Why do you make me drag it out of you bit by bit?"

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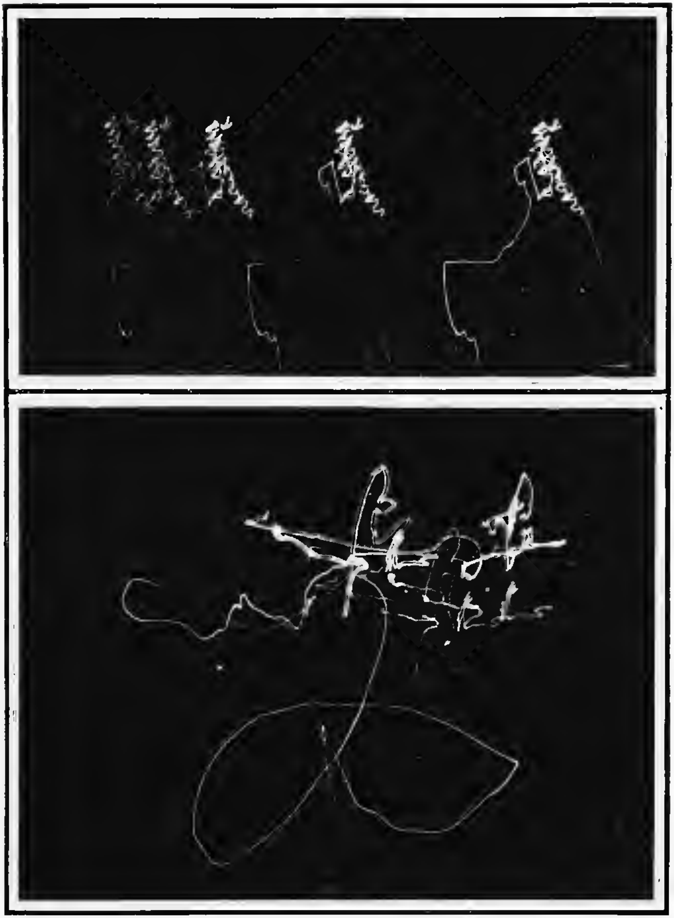
passenger sitting in the moving train and looking at the stationary train is often deceived. He sees the other train, or rather he believes he sees the other train, moving away, and a little later he is greatly surprised to find that it is he himself who is moving. Of course the illusion can only occur when the train carrying the observer moves very gradually and very smoothly. A sudden jolt would immediately dispel the illusion. No person really doubts to-day that our earth is moving through space, that it is spinning round like a top, and at the same time making a continuous journey around the sun. The only reason why man was deceived so long was that our planet glides along without any resistance being offered to its motion. The railway passenger may discover the motion of his train by a sudden jolt, but it is fortunate that man has not experienced any similar jolting of the planet.

It was a bold theory to bring the sun to a standstill and set the earth in motion. We know how poor Galileo had to suffer imprisonment at the hands of the Church for supporting this theory, which had been proved seventy years previously by Copernicus. However, astronomers were able to bring forward so many observed facts to support this theory that its truth was forced upon every thinking person. It took some time to convince people, for the earlier theory seemed the more natural, but there could be no doubt that it must be the one way or the other.



PROVING A THEORY

The upper illustration was sent to me as a photograph of a flash of lightning, and the puzzle was how the flash had repeated itself five times on the photographic plate. When it was suggested to the photographer that this was not a photograph of lightning but the lights from five street lamps, he could not accept this theory as he felt confident that he had photographed a flash of lightning. However, he agreed to test the matter by setting up his camera in the dark with the shutter open as before, and with a street lamp at some distance, whereupon he obtained the second photograph. This proved clearly that the suggested theory was correct; the writing appearance being due to the movement of the camera in setting it up.

There is a good story told in this connection of a well-known professor examining three raw students. He asked the first, "Does the earth go round the sun, or the sun go round the earth?"

"The earth goes round the sun, sir." "You," said the professor, quickly turning to the second student. "Oh! the sun goes round the earth." "You," demanded the professor of the third student. "Oh! it's sometimes the one way and sometimes the other." This was the only alternative left for the poor fellow.

Our position then is this. We gather a number of carefully observed facts together, and we then try to explain them. We call this attempted explanation a *theory*. We then look out for new facts and see if our theory can explain these also. If it cannot we must be willing to alter our theory or to construct a new one (see illustration facing page 18).

We have another and important method of testing our theories. We may be able to reason from a theory that certain things should happen or should exist if our theory be true; we look out for these facts and find if they really do exist. We must follow up a theory to its logical conclusion and test our deductions by careful experiment. A theory then is a good thing whether it proves to be correct or not; it assists in furthering and systematising the collection of facts. Lord Bacon summed up the matter, three centuries ago, in the following sentence, which is to be found in his "Advancement of Learning": "All true and faithful natural philosophy hath a double scale or ladder,

an ascendant and descendant; ascending from experiments to the invention of causes, and descending from causes to the invention of new experiments."

When we are quite satisfied that a theory is correct—that it explains all the facts which have been observed—we then raise the theory to a higher platform and call it a *Law of Nature.* It is well to remember that, with all other knowledge, these laws of nature are of man's own making. It is amusing how some people think that certain things happen and are bound to happen because of these "laws of nature." As if the universe were controlled by these laws which man has constructed! The laws of nature are only theories which seem to be correct; they are not facts, but merely our views or ideas of facts.

CHAPTER II

WHAT THINGS ARE MADE OF

Adding things together—The ingredients of the world—Two causes of substances being rare—Chemical combination—Curious partnerships—Invisible particles of matter—Atoms—Molecules—Chemical affinity—Electrical attraction—Two different electricities—The origin of the terms positive and negative—The structure of matter—An analogy—Cohesion—Temperature—Solid, liquid, and gaseous

THE inquiring mind is not satisfied to know that certain things are made of a substance called glass and other things of another substance called clay. We want to know what these substances themselves are made of.

Before we left school we had become quite accustomed to the idea that most things are made by adding other things together. We were interested to learn that one kind of glass was made by boiling sand, soda, and lime together, after the manner of making toffee. We were, in our early days, amused to find that paper could be made from any old rags. We soon began to realise that man could only add things together or subtract some things from other compound things; that there was only a certain definite amount of matter in the world, and that this had existed from the beginning, when "God created the heavens and

the earth." We soon realised that everything we see upon the earth to-day existed in some form from the beginning of time. Indeed, we became convinced like Solomon of old that "there is nothing new under the sun."

We had not gone very far in our inquiries when we learned that all compound substances are merely different combinations of a certain number of simple or elementary substances. While we have two or three hundred thousand different compound substances, we find that they are all composed of two or more of a limited number of simple *elements* or fundamental substances.

At present we know of some eighty elementary substances, and the general reader is only conversant with a comparatively small number of these. If one examines a complete list of the elements, as given in Appendix I., at p. 322, it will be found that most people could not recognise the half of the names.

A certain number of the elementary substances are well known to us; more especially the following metals, which I have placed in the order of their commercial monetary value: *Platinum*, *Gold*, *Silver*, *Nickel*, *Mercury*, *Aluminium*, *Tin*, *Copper*, *Zinc*, *Lead*, *Iron*. Then we all feel somewhat familiar with the gases—*Oxygen*, *Hydrogen*, *Nitrogen*, and *Chlorine*. Leaving metals and gases, we come across the name *Carbon*, which substance we know to occupy a very important place in the universe, and even in our own

bodies. We are composed chiefly of Carbon, Hydrogen, Oxygen, and Nitrogen.

Returning to the list of the ingredients of the world, we find a number of other elements with which we have some acquaintance, such as *Phosphorus*, *Sulphur*, *Potassium*, *Sodium*, *Arsenic*, *Antimony*, *Bromine*, *Calcium*, *Cobalt*, *Iodine*, *Magnesium*, *Selenium*, *Silicon*, and *Uranium*. To these we have to add *Radium*, which remained a hidden treasure in nature until a few years ago; the discovery of which has proved of immense importance to science, as we shall see later.

So far I have only mentioned thirty-one of the known elementary substances. I doubt if the general reader will recognise any of the remaining ingredients of the world. Here are half-a-dozen of the most curiously named—*Yttrium*, *Xenon*, *Vanadium*, *Praseodymium*, *Krypton*, and *Gadolinium*.

Many of the elements never appear upon the lists of chemicals for sale, and some have only been obtained with great labour and care in the scientific laboratory. We must remember, however, that a substance may be worth much more than its weight in gold from two totally different causes. The element may only occur in very small quantities in the world, or it may be that nature has so locked it up in some compound substance that we require to expend an enormous amount of energy to separate it. For instance, you may buy a barrel of lime for a few shillings, and we know that more than half of the ingredients of the lime is composed of an elementary

substance called *calcium.* Suppose you said to the seller that you would prefer to take only the calcium which was contained in the barrel of lime. You were aware that nearly three-quarters of the whole contents were calcium, but you would be quite pleased with half a barrel. If the seller were to carry through the contract you would be rather surprised at his account. Perhaps you had been willing to pay the total price of the barrel of lime, or it may be that you were expecting some reduction seeing you were only asking for part of the contents of the barrel. Presuming that you really had no previous knowledge of the value of calcium, you would certainly think there was some mistake in your account, for it would not be less than fifty pounds, instead of the few shillings you had expected to pay. It is strange, at first sight, that any ingredient of common matter should cost so much money, and yet be so plentiful in nature. The comparatively high price of the calcium is due to the expense of separating it from its compounds. Some years ago the price of the metal calcium was very much higher, as the means of producing it then were still more expensive.

Thinking once more of the list of the fundamental substances, one might suppose that if a man knew the individual properties of each element, he should be able to tell the properties of all the compounds formed out of these. Far from it, for when these elementary substances are in partnership with each other they have entirely lost their individuality. It

would seem quite natural to suppose that if we combine two gases together we should merely make a compound gas. It is true that we may easily make a mixture of gases, but then that is just similar to mixing sand and sugar together; each retains its own individuality. That is a totally different thing from chemical combination.

When we were taught at school that ordinary water was nothing more or less than a chemical combination of two gases, hydrogen and oxygen, we found it very difficult to realise this fact; it was certainly not what we should have expected. Is this only a *theory*—that water is made of two gases, and nothing else—or can we prove it? The fact is very easily demonstrated, for if we pass a current of electricity through a vessel containing water, the water gradually disappears, and if we adopt means of collecting the gases rising from the water, we find that we have nothing but hydrogen and oxgyen. (See illustration facing page 314.)

You will notice how very completely these two elementary substances lose their individual properties when they enter into partnership with one another. We know that hydrogen is a very inflammable gas, but no sane person would attempt to set water on fire. Then, again, many of us have boyhood recollections of some beautiful experiments with oxygen gas. We found plenty of amusement in burning all sorts of things in a bottle containing oxygen. We even succeeded in burning pieces of steel watch-spring,

object he has been looking at is quite invisible to the unaided vision—so small that it cannot be seen even as a speck (see illustration facing p. 38). Here, indeed, we have something very minute in size, and yet these microbes are great giants compared with the particles of which matter is composed. Why, these very microbes each contain many thousand millions of tiny particles. Surely we need not go farther; we can never hope to form an adequate mind-picture of the size of these tiny bricks of nature. We must simply picture all matter to be composed of extremely minute particles, which we call *atoms.*

There will be just as many different kinds of atoms as there are different elementary substances. There is the atom of iron, the atom of gold, the atom of hydrogen, the atom of oxygen, the atom of carbon, and so on; some eighty kinds of atoms being known. We do not speak of an *atom* of water, for the smallest particle of water which can exist as water is made up of two atoms of hydrogen combined with one atom of oxygen. This little combination of atoms we call a *molecule* of water. It is clearly the smallest particle of water which can possibly exist; for if we split it up it is no longer water, but becomes hydrogen and oxygen gases.

A *molecule* is a group of atoms, but the atoms may be all of one kind. We may speak of a *molecule* of hydrogen, but then it is merely composed of two or more *atoms* of hydrogen linked together. The molecules of some compound substances are composed of

a large number of different atoms. For instance, a single molecule of the compound known as alum contains at least a hundred atoms, while the number of atoms in each molecule of some other compound substances is nearer a thousand.

We now picture the elementary *atoms* grouping themselves into little congregations called *molecules.* We picture the atoms grabbing hold of one another, and we find that the different atoms have different grabbing powers. For instance, when we combine hydrogen and oxygen together, each oxygen atom is able to grab two hydrogen atoms to itself. Therefore when we break up water into its constituent gases, by means of an electric current, we find that we get twice the volume of hydrogen that we get of oxygen. The copartnery agreement of the combination known as "Water" reads that there shall be two members of the Hydrogen family and one only of the Oxygen family in the combination.

In our common table-salt there is a very simple copartnery—one atom of sodium combining with one atom of chlorine. Then again a single atom of gold will grab three atoms of chlorine to form the chloride of gold used in toning photographs. Other kinds of atoms are capable of grabbing four atoms, while yet some others have a greater appetite. The atoms of some substances such as nitrogen and carbon have various grabbing powers. Sometimes a nitrogen atom will grab one atom, sometimes three, and at other times five atoms. However, all we desire to

notice at present is that the different elementary atoms unite together in a great variety of ways, and thus form the molecules of all compound substances.

We used to be taught at school that the atoms combined together by a force called *chemical affinity*, but as to the nature of that mysterious force we could receive no enlightenment. It is only within comparatively recent years that we have recognised the fact that *chemical affinity* is nothing more or less than *electrical attraction* between the different atoms. We are all familiar with the phenomenon of electrical attraction. Perhaps we have only seen it in the form of an electrified rod attracting pith-balls or feathers, but that the phenomenon may be observed with common every-day articles is shown in the photograph facing page 54. Here we see an ordinary flower vase, which has been well dried and briskly rubbed with a silk handkerchief, attracting a bunch of feathers.

But we know that all bodies charged with electricity do not attract each other. In the very earliest days of experimental electricity it was observed that when a glass rod was electrified, by rubbing it with a silk cloth, the electrification was not the same as that of a rod of sealing-wax similarly "excited." If one light body was electrified by the excited glass rod, and another light body was electrified by the sealing-wax, those two light bodies did attract each other, but if the two bodies were electrified from the same source they invariably repelled one another. Two pith-balls

charged by the glass rod repelled each other, and if both were electrified by the sealing-wax the same repulsion took place. It was therefore quite evident that similarly electrified bodies—or, in other words, bodies charged with the same kind of electricity—would repel each other (see illustration facing p. 66). It was also apparent that the electrification from the glass rod was not the same as that from the sealing-wax; for a body charged by the glass rod would not be repelled, but would be attracted by a body charged from the sealing-wax.

At first experimenters called the electricity produced by glass rods *vitreous*, and that from sealing-wax *resinous*. When, however, it was suggested by Benjamin Franklin that electricity was a single mysterious fluid, he concluded that a body electrified by a glass rod had an excess of the fluid, and so he said it was *positively* electrified, or charged with *positive* electricity. On the other hand, he supposed that a body electrified by sealing-wax had a deficiency of the electric fluid, and so he said that it was *negatively* electrified—or, in other words, he said that the sealing-wax produced *negative* electricity.

After a while people began to think that it was quite ridiculous to speak of electricity as a fluid, but for convenience' sake they retained the names positive and negative electricities. To-day we have returned to ideas not unlike Franklin's fluid theory; but we shall understand this better when we come to deal with the present ideas concerning the structure of the atom.

In the meantime, we shall be content to picture some of Nature's atoms as being positively electrified, while others are negatively electrified; and we are familiar with the idea of two oppositely electrified bodies attracting each other. The hydrogen atom is *electro-positive*, while the oxygen atom is *electro-negative;* these two will therefore attract one another and become electrically united, or, if we choose to call it so, we may say that they are chemically united. We must be content to accept this general statement until we are in a position to see later how the atoms become electrically charged. We shall see also how it is that atoms of the one kind become electrically united.

So far we have formed quite a useful mental picture of the structure of the molecules of matter. We see the elementary atoms with their electrical charges combining together, and thus forming the neutral molecules. But even these molecules are far below the range of the most powerful microscopes. We think of the invisible microbe again, and try to realise that it contains millions upon millions of individual particles, or molecules, each of which contains several atoms. We therefore picture a piece of solid iron as being entirely composed of invisible atoms of iron.

The idea that a solid lump of matter can be entirely composed of invisible things seems strange to some people, but there is nothing mysterious in this. Imagine yourself standing on some country-side through which a very wide and dusty road passes. The road after many windings goes up the face of

a far-distant hill, but as the white road is very wide it is quite easy to follow its track on the distant hill-side. You observe a man making his way along the road towards the distant hill. As he proceeds on his journey you observe that he appears to get smaller, and by the time he reaches the far-distant hill he is not visible even as a speck on the white road, which we are supposing to have been made exceptionally wide to suit our present purpose. The hill is so very far away that even with a telescope you fail to see the man. If you could never get any nearer to the man he would remain invisible to you, but if a great army of many millions of men appeared on the distant hill-side you would then observe a dark patch. Here we have the visible lump of solid matter composed of particles which are quite invisible to us.

If we handle a piece of solid iron it is very apparent that the invisible particles of which it is composed must have a tremendous grip of one another. To this force which binds the molecules together we have given the descriptive title of *cohesion*, from the Latin word *cohæreo*, meaning *I stick*. It is easy to demonstrate the immense force with which the molecules cling on to one another; for if we take a bar of iron—such as is used for making rivets, and measuring about one square inch in section — we find that it requires a pull equal to about twenty-five tons to draw the molecules asunder at one place. Some steel wire will stand a stress up to one hundred tons per square inch. When we have succeeded in wrenching the

molecules apart we need not place the severed parts together in the hope that the molecules will cling again to each other. It is apparent, therefore, that the molecules require to be very, very close together before they can attract one another. If we heat the severed ends of the iron bar, we enable the molecules to get within close range of each other again, and we find that, when the bar has cooled, the little particles have taken a powerful grip of one another again. To form a clear idea of what happens in this case we must try and picture the structure of solid matter.

It almost goes without saying, that the molecules are not like little solid bricks closely packed together. We shall see later that we have definite experimental proof that spaces do exist between the molecules. We must picture all matter—even the most solid thing we can think of—to be in reality porous; steel, flint, marble, glass, all are like sponges.

Further, we have long ago recognised the fact that these little invisible particles can quiver or *vibrate*, and that this vibration of the molecules is what we popularly call its heat or *temperature*. We may set the molecules of iron into a state of very rapid vibration by striking it with a heavy hammer. The iron soon becomes so hot that we cannot touch it with safety, and if we continue the hammering we soon make the iron red-hot. Every body has some heat; if it has very little heat we say it is cold, but that is merely by way of comparison. If the temperature of

the air in your sitting-room is 75 degrees Fahrenheit (about 24 degrees Centigrade) you say it is unbearably hot, but if your tea were served at the same temperature your remark would be that it was ridiculously cold. A cold body could still be colder, therefore it possesses some heat, and therefore its molecules are in a state of quiver or vibration. Consequently we picture the most dense solid as being composed of isolated particles which are continually in motion but never in actual contact.

Let us now consider the case of the severed bar of iron. We heat the two ends either by hammering or by placing them in a source of heat. In a fire we have the molecules in a state of rapid vibration, and these set the molecules of the iron into a similar condition. If we apply a very intense heat to the iron we cause its molecules to make such long excursions that they cannot attract each other so well as previously; they let go their firm hold upon each other, so that the solid becomes a liquid mass. If we continue to apply a very intense heat, the molecules completely lose their hold upon each other, and the liquid mass becomes a vapour or gas. But before the molecules have been driven apart from their *solid* grip, wrought iron must be raised to a temperature of about 3000 degrees Fahrenheit (about 1700 degrees Centigrade), and before the little particles have been freed from their *liquid* grip a further increase to 6000 degrees Fahrenheit (3300 degrees Centigrade) must be attained. As soon as the force (heat), which is driving the molecules

apart, is withdrawn, the molecules once more get into grips with each other returning from the *gaseous* condition to the liquid and then to the solid, provided that is their natural condition at ordinary temperatures.

We take one more glance at the picture already drawn of the construction of matter. We see all bodies to be porous, and all composed of vibrating molecules which are not in actual contact with one another even in solids. We find the attractive force of *cohesion* to be very much greater when the molecules are closer together as in a solid, than when farther apart as in a liquid. In a solid we picture the molecules merely swinging to and fro like little pendulums, whereas in a liquid we picture the molecules, not only possessing this quivering motion, but also being in some measure free to move about and glide over each other. If we mix milk and tea together the molecules of the one liquid quickly pass among the molecules of the other. That the molecules of liquid will move about, of their own free will, may be demonstrated by a simple experiment. If we have a glass vessel partly filled with a solution of copper sulphate—commonly known as blue-stone—we may gently pour a quantity of water on to the top of this blue liquid. At first we see the two liquids quite separate, but gradually we find the molecules of the copper sulphate making their way upwards, against the force of gravity, and if left alone for a considerable time, we observe from the colour that they have permeated the whole water.

This phenomenon of *diffusion* is much more apparent when the molecules have got completely beyond their attractive distance of one another as in a gas. No matter how small a quantity of gas is let free in a glass vessel, the gaseous molecules quickly spread themselves throughout the whole space available. If the stopcock of a gas-bracket is left open and gas allowed to escape into a room, we soon become aware of the presence of these molecules although we may be at some distance from the gas-bracket. The molecules do not take long to make their way among the molecules of air and with it enter our noses and stimulate the olfactory nerves which, acting upon the brain, produce the sensation of smell.

So far we have dealt with three different conditions of matter—solid, liquid, and gaseous—and in the following chapter we shall consider what has been called by some the fourth condition of matter.

CHAPTER III

THE STUFF THAT ATOMS ARE MADE OF

The idea of atoms is very old—Have we proof that there are particles smaller than atoms?—Weighing invisible objects—How these smallest particles were discovered—Some interesting electrical experiments—Suggestion of a fourth state of matter — The electron — What we have found out about electrons—They pass through a solid metal—The simple relationship of energy, velocity, and mass—What the electrons are—The size of an electron

BEGINNING with a lump of solid matter, we have seen that it is built up of isolated particles called *molecules*, and that these invisible molecules are composed of smaller elementary *atoms*, which are electrically united together to form the molecules.

Our next question is—What are the atoms made of? Without giving the subject much thought, some one might reply that the atoms are made of gold, iron, hydrogen, and so on, naming all the elementary substances known to the chemist. But that does not tell us anything of the nature of the atoms; these are merely names which we have given to certain forms of matter which we find we cannot break up into any other substances in the way that the multitude of compounds may be analysed. A certain bright-yellow, and much-sought-after, metal we call *gold*, but the

by direct experiment that particles smaller than atoms do exist. It may seem to the reader rather ridiculous to say that we can definitely prove the existence of such very small particles, when even the giant molecules and atoms are hopelessly beyond the reach of the most powerful microscope. His surprise will not be lessened when he learns that we can measure and weigh these ultra-microscopic particles—just as surely as we can measure and weigh our own world and its neighbouring planets.

Perhaps a rough analogy may be of some service at the very outset. We cannot see a rifle bullet as it flies through the air, but if we put an obstacle in its path we soon become aware of its presence. We could tell the velocity of a bullet without ever seeing it. The speed of projectiles has been determined by means of an instrument called a chronograph. This piece of apparatus is used largely in observatories for recording the exact moment at which any observed phenomenon occurs. The moment that the observer sees a star cross a spider-web line in the eyepiece of his telescope he presses an electric push, and the chronograph, which may be situated at some distance, records the exact time at which the contact was made. In passing, it may be of interest to note that the apparatus consists of a large cylinder driven round by clockwork at a definite rate. A pen travels slowly along the cylinder after the manner of the trumpet on a phonograph. At the end of each second the pen strikes a paper encircling the cylinder

and leaves a dot, thus spacing the paper off into seconds. The pen is also under the control of the distant observer; when he presses the push the pen makes an additional dot. Its exact position not only indicates the particular second of time but the thousandth part of the second during which the dot was made.

In recording the speed of a flying projectile two screens are erected at a measured distance from one another, and as the flying bullet passes through these it makes an electrical contact at each screen, and causes the chronograph to record the exact time at which it passed these two points. In this way the velocity of the bullet is determined. No one will suppose that we are going to find out about the particles, of which atoms are made of, in this exact fashion. I merely use this as a rough analogy of how it is possible to gain exact information concerning an invisible object.

First of all we wish to see how it was that these invisible particles composing the atom were discovered. The story is an interesting one. It had been known for a long time that an electric spark will pass more easily through a vessel or tube of rarefied air than through the denser air at ordinary atmospheric pressure. A very simple way of demonstrating this is to attach an "electric egg" to an air-pump, as shown in the photograph facing page 78. The glass vessel is merely called an egg because of its egg-like form. It is furnished with two brass rods,

one of which is fixed to the base of the egg, while the other slides through an air-tight passage at the top. The whole vessel is air-tight, having an outlet at the base which may be connected to the air-pump. By arranging wires from the two brass rods to the terminals of an induction coil, connected to a battery, electric sparks can be made to pass between the two little brass rods within the egg. We gradually separate the rods until the sparking ceases, owing to the intervening air-space offering too much resistance to the discharge.

If we now pump out a little air we soon find the sparking to recommence, showing that the thinner or more rarefied air is a better conductor. As we go on withdrawing the air we observe that the sparking changes into a silent stream or thread of luminosity. As the "vacuum" increases, the whole egg becomes illuminated with a glow, then a little later the luminosity breaks up into a number of narrow horizontal discs or slices. We now find that the air has become so rarefied that it has overstepped its good conducting qualities, and we require to apply considerable electrical pressure to cause a discharge to pass through this high vacuum.

A number of interesting phenomena occur as the exhaustion proceeds, and it may be remarked in passing that an ordinary mechanical air-pump, such as shown in the photograph, will not be able to produce a good enough vacuum to obtain all these phenomena, so that some other means, such

as a mercury air-pump, has to be adopted. However, what we wish to notice at present is that when the exhaustion has reached a certain point all the glow disappears from the interior of the globe, and all would appear totally dark but for the fact that when this high state of exhaustion is reached the walls of the glass vessel begin to glow with a greenish phosphorescence. The colour of this phosphorescence varies according to the ingredients of the glass. But what is causing the glass to phosphoresce?

Sir William Crookes, of London, who has done so much of the pioneer work in this branch of science, pictured a stream of radiant particles being shot like bullets from the cathode terminal. These invisible bullets strike the glass walls of the tube and cause them to phosphoresce. If the air is not practically all withdrawn, its remaining molecules suffer bombardment and these become luminous, producing the glow which at first filled the electric egg, and which may be seen in the ordinary vacuum or "Geissler" tubes.

Crookes suggested that here we had matter in a *fourth* state. In other words, we had only been familiar with matter in three conditions—solid, liquid, and gaseous. In the solid state we had the molecules of matter holding on very firmly to one another. In the liquid state they had in a great measure lost this hold and were therefore farther apart and free to roam about among themselves. In the gaseous state we had the molecules still farther separated, all on the move, colliding against each other, and apparently repelling one

another. In the newly discovered fourth state, Crookes suggested that they were "in a condition as far removed from the state of a gas as a gas is from a liquid."

Crookes spoke of this state as *radiant matter*. It was indeed a bold suggestion, but we shall see later that his surmise has turned out to be correct. At the time, however, this idea was not accepted; the general belief was that these flying particles were ordinary material atoms. To-day the physicist has weighed and measured the flying particles, and he has found them to be very much smaller than the smallest known atom, which is the hydrogen atom.

At the time of Sir William Crookes' discovery these flying particles were called the *cathode rays*, because they were shot off by the cathode electrode.[1] Later on Dr. Johnstone Stoney christened the particles "electrons," while Professor J. J. Thomson, of Cambridge, who has done so much in investigating the structure of the atom, prefers to call them "corpuscles." Possibly the word *electron* will be more distinctive to the general reader; he cannot confuse it with any other existing word. He is, therefore, better able to keep the idea of the electron apart from ideas of ordinary matter. We already have the word *corpuscle* signifying a minute animal cell, and although

[1] The *cathode* is the name given to the negative or leading-out electrode of the tube. The positive or leading-in electrode is called the *anode*. Some people find it difficult to remember which electrode is the anode and which the cathode, but if one thinks of the electric current entering and leaving, the words come in their alphabetical order—*a* before *c*—anode (leading-in) and cathode (leading-out).

there cannot be any confusion between blood corpuscles and these flying particles in the vacuum tube, yet the word *corpuscle* is more suggestive of ordinary matter than the word *electron* is. I shall, therefore, keep rigidly to the word *electron.*

Looking at a highly exhausted vacuum tube, through which an electric discharge is passing, we do not see the stream of flying electrons ; they are quite invisible. We see only the glass phosphorescing under the bombardment of these invisible bullets. By making the cathode terminal of a saucer shape, we can focus the shower of electrons to one spot on the glass. When we do so we find that their path is always a straight line. Here comes a fact which will seem very strange. When a magnet is brought near the vacuum tube, we see that the stream of electrons has been deflected from its straight path, for they strike the glass at a lower point. The more powerful the magnet the greater will be the deflection of the electrons. All this will seem strange to the reader who learned in childhood that a toy magnet would attract pieces of iron and steel but nothing else. Most of us have become familiar with the fact that an electric current will be deflected by a magnet ; indeed, it is this force which turns the wheels of our electric tramway cars and all other electrically driven machinery. This stream of electrons within the vacuum tube is similarly deflected by a magnet, so it is apparent that the moving electrons behave exactly like an electric current.

It is natural to suppose that these flying electrons

are negatively electrified particles because they are shot off, or repelled, by the cathode or negative electrode. This fact may be demonstrated in many ways, perhaps the simplest being to notice the direction in which the electrons are deflected by a magnet.

It would be a very laborious task to count all the sovereigns passing through the Bank of England. Indeed the officials themselves do not trouble to count out each thousand sovereigns. They simply weigh out a certain quantity, and they know that they have then a certain number of coins on the scales. The task of actually counting the sovereigns in the Bank of England would, however, sink into insignificance if one were asked to count the number of invisible dust-particles in the air of a room. A very clever experimenter, Aitken, of Falkirk (Scotland), devised means of counting the number of dust-particles in the air. I have given a description of Aitken's experiments in Appendix No. IV., at page 335, as these help us to understand an even greater feat—the counting of electrons. At present we are going to accept the statement that it has been found possible to count the electrons, and those who are willing to trouble with the details relating how this seeming impossibility has been accomplished will find a general description in the appendix referred to.

From what follows, it will be seen that to be able to count the electrons helps us to gain further information about these invisible particles. For instance, it is an easy matter to determine by experiment the

total amount of electrification carried by a quantity of electrons, and being able to count how many electrons there are, we can tell, by a simple division sum, the amount of electricity carried by each electron. We have seen already that the electron is negatively charged, so we know further the amount of negative electricity which it carries.

We shall be content to deal with general statements here, leaving the details to be dealt with in the Appendix.

Very elaborate experiments were carried out originally to determine the speed of the flying electrons in a vacuum tube, and the calculated velocity turned out to be enormous. It was found later that by subjecting the stream of electrons to the deflecting power of a known magnetic field, and also to the deflective influence of an electric field, the velocity of the particles could be determined more easily. The results of these experiments agreed with those got by the more elaborate methods.

It was found that the speed of these flying electrons varied under certain conditions. As the electrons are shot off from the cathode terminal of the tube by means of an electric discharge, it is a natural consequence that their velocity will depend in part upon the intensity of the electric discharge. Then it is easy to realise that the velocity will also depend upon the degree of vacuum existing in the tube; the molecules of air remaining in the tube will be in the way of the flying particles and will impede them. If the exhaustion

is not very good, or "high," the speed of the electrons may reach five thousand miles per second. This is an enormous speed compared with that of a rifle bullet which travels only about one-third of a mile in a second. However, five thousand miles per second is by no means the top speed of the electron. Provided with a clear path in the form of a high vacuum, and impelled by a considerable electric force, the electrons will fly across the vacuum tube at a speed of sixty thousand miles per second, or roughly about one-third the velocity of light. It is difficult to realise what such a speed means. We might think of it as thirty times across the Atlantic in one second, or from here to the moon in less than four seconds; but we must not imagine that it is possible to shoot electrons across the Atlantic. We must provide them with a clear space—a good vacuum—if they are to attain these high velocities.

The foregoing suggests the question—Can electrons be made to fly through the air? It will be clear that we cannot produce a stream of these electrons at all unless we have a fairly good vacuum; it was only when we had withdrawn some air from the electric egg that the sparking changed to a luminous thread and ultimately to an invisible stream of cathode rays—or in other words, flying electrons. We picture the cathode terminal shooting the electrons off with great velocity, but only to be stopped by the glass walls of the tube. Could we not form a window of some kind through which the electrons might continue

their flight into the open air? I should not be the least surprised to hear some one say that this would be quite impossible, for any window that would let the electrons escape would surely let the air into the tube and the necessary vacuum would be gone. The argument seems reasonable, but the facts prove it to be wrong. Professor Lenard, of Germany, succeeded in making a vacuum tube with a window that would not let the air in and yet would allow the flying electrons to escape. Judging from appearances his window looks much more like a "shutter." It was made of a thin sheet of solid aluminium metal. When the flying electrons within the tube reached this solid metal window they were not held up but passed right through it. How did the professor know that they had escaped? They are invisible. Although he could not see the flying particles he saw their track in the open air, for as soon as they escaped through the window they met with serious obstruction from the surrounding air. The molecules of gases forming the air were subjected to the bombardment of these invisible bullets, and a faint phosphorescent glow was produced, somewhat similar to that produced in an ordinary geissler tube. The visible effect is small and can only be seen in the dark, and only in the immediate neighbourhood of the aluminium window. If, on leaving the aluminium window they enter a second vacuum tube, they will produce a very distinct glow. However, their presence may be detected in the open air by means of a phosphorescent screen.

The flight of the electrons in the open air is quickly ended; they cannot escape farther than about one inch from the tube. What becomes of them? Do they fall down like spent rifle bullets? As soon as they have escaped they become attached to the gaseous atoms of the air. In short, they are absorbed by the atmosphere.

When these flying electrons escape into the air they are called *Lenard rays*, after the brilliant experimenter, who so successfully plotted a way of escape for the imprisoned particles. It must be understood, however, that they are in reality the same cathode rays or stream of electrons which we have within the tube. As a matter of fact, Lenard himself believed that the cathode stream was merely a stream of æther waves or pulses. When Professor Schuster made some calculations which gave clear proof that the cathode stream and the Lenard rays were composed of particles the idea seemed at first to be ridiculous. It was some years before Lenard saw that Schuster was right.

When scientists were convinced that the cathode rays were a stream of particles, Professor Lenard's experiment had a great deal of significance attached to it. The fact that these particles could pass through a solid sheet of metal foil, through which the atoms of the gases contained in the air could not pass, was surprising, and seemed to indicate that these particles were extremely small. The smallest atom is that of hydrogen gas, the lightest substance known, and yet that gas could not pass through the aluminium window.

We have seen that the velocity of flying electrons has been determined, and it is of interest to know that the mass of the electron, and also the energy exerted by the flying particle, have also been determined, as will be explained in Appendix IV. These three factors lead us to a very interesting discovery.

It may be that some reader does not see clearly the relationship of energy, velocity, and mass, but a rough analogy should make the matter plain. It requires a certain amount of energy to drive a nail into a log of wood. If the carpenter selects a very light hammer he must bring it down very rapidly upon the nail. In this case we have a small mass, the hammer, moving at a comparatively great velocity. If, on the other hand, the carpenter uses a heavy hammer, he finds that a comparatively slow velocity is sufficient to drive the nail home. The same work may therefore be done by a small mass moving at a high velocity as by a greater mass moving at a lower velocity. I am leaving out of account the loss of energy, which is not the same in both cases. We have the three factors to take into account—the amount of energy necessary, the velocity, and the mass. It will be clear that if any two of these factors are known the third may be found by calculation.

In a former paragraph I mentioned the electric charge of electrons. What bearing does this have upon the subject? It has a very definite meaning. The mathematician has clearly proved that the *inertia* of the flying electron is entirely due to its electrical

charge, and in fact that there is no electron apart from the electric charge. This is indeed a strange thought, and very difficult to grasp at first. *An electron is nothing more or less than an electric charge in motion—a unit or atom of negative electricity.*

It is, of course, quite impossible to form any mental picture of the actual size of an electron. To say that it has about a thousand times less mass than a hydrogen atom does not help us very much, for we have no mental picture of the size of a hydrogen atom. To say that it would require a regiment of one hundred thousand electrons placed in a row to make up the diameter of a molecule of ordinary matter, would only indicate the relative sizes of these two ultra-microscopic objects. Sir Oliver Lodge has suggested the following interesting analogy to help us to realise the relative size of these electrons to the atoms in which they exist.

Imagine a church one hundred and sixty feet long, eighty feet broad, and forty feet high. The space contained in this building is to represent an atom of matter. Looking at this enormously magnified atom, we should have great difficulty in seeing the electrons contained in it. Each electron would be no larger than the dot or full-stop at the end of this sentence, and yet we shall see that these electrons are the stuff that atoms are made of.

CHAPTER IV

THE CONSTRUCTION OF THE ATOM

The electrons within the atom—Some analogies—A miniature solar system—Different kinds of atoms—A picture of the atom—Interesting experiments with floating magnets—Family groups of atoms—Newlands' octaves—The periodic law—A bold prophecy—Electro-positive and electro-negative—An analogy—The atoms in partnership—Matter and electricity.

We wish to form some reasonable picture of the atom composed of these infinitely small electrons.

It will be apparent that if the atom were built up of electrons in the same way as a wall is composed of bricks, a tremendous quantity of connecting cement would be required to fill in the spaces between the electrons. Picture the church in Sir Oliver Lodge's analogy, as described at the close of the preceding chapter. Try and imagine a few hundred small dots spread throughout its whole interior. There would be somewhere about a hundred feet of empty space between each tiny dot. But we are not to think of the electrons as being fixtures in the atom in the sense that currants are fixed in a cake.

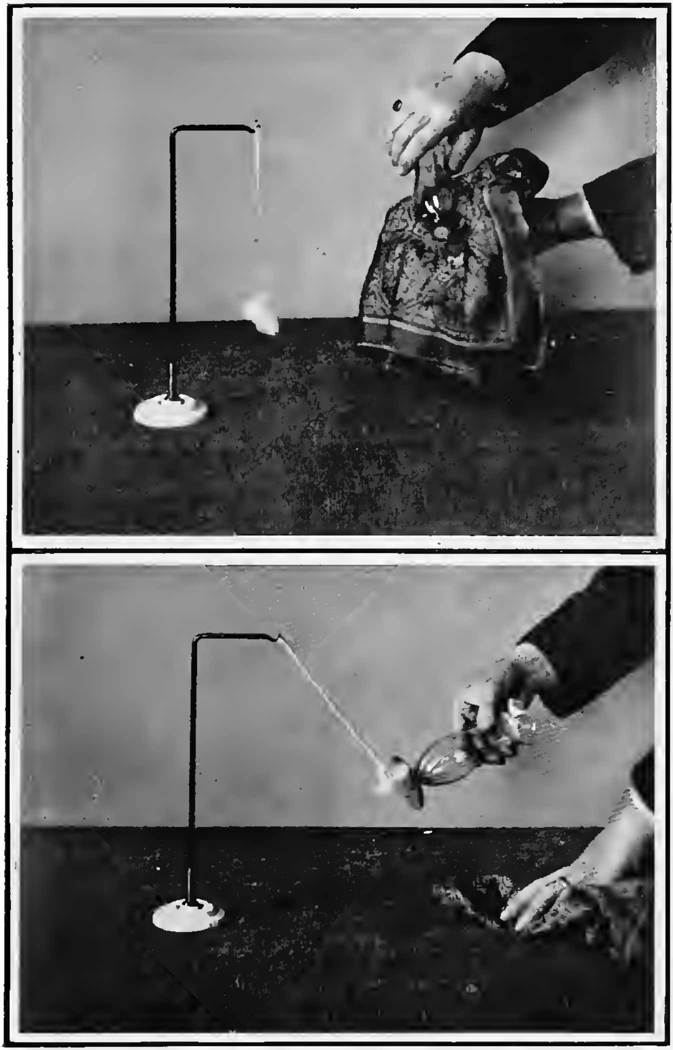
In our school-days some of us used to play a game in which the boys were divided into two parties. One party took possession of some rising ground and tried

to guard it against the attacks of the other party. Now it is evident that unless we had enough boys to form a complete protecting wall around the "castle," we had to keep a good lookout for attacks at different quarters. This was where the sport came in. Each boy did his best to look after one particular section, and it was only by rushing hither and thither that we could hope to keep the enemy out. In other words, one boy by keeping on the move was able to do the work which otherwise should have been done by a number of boys placed in fixed positions. If the defending party were successful then the protected space was as good as a solid square of boys. We picture the electrons defending the atom by rushing about from one point to another, with this difference, however, that while the boys made excursions in all directions as required, the electrons are moving in regular orbits.

Perhaps another analogy may help to make the matter quite clear. Picture a child playing with a hoop, and it is apparent that when the hoop is struck by the child's stick, the hoop behaves just as though it were a solid disc of equal weight; the enclosed space is protected by the surrounding hoop. Imagine this hoop hung up in a horizontal position by some invisible threads. We may strike it at any part of its circumference and it is just as though we had a large solid disc before us. Suppose, however, that instead of a continuous hoop, we had a regiment of small balls placed in a circle and leaving spaces between each ball and its neighbours. You might strike be-

tween the balls and there is no idea of solidity there, but let the circle of balls be set revolving at a high speed, and if you then strike the circle your stick will rebound just as though the circle were solid. It will be apparent that the velocity must be great, but it is not difficult to imagine the velocity being so great that the balls might be placed at some considerable distance from each other. If the velocity is increased in a corresponding manner we may still have the effect of a solid mass. This gives us a very rough picture of the atom of to-day; a congregation of electrons revolving with enormous velocity in regular orbits. We can see now how the far-scattered dots are able to occupy the whole interior of the church, in the analogy already referred to.

We see that the atom of to-day is in reality a miniature solar system. We need not necessarily picture it as a circle of electrons all in one plane; the mathematician merely prefers this arrangement because it enables him to treat the subject best from a mathematical point of view, and to make many interesting deductions. However, we are not going to trouble about mathematical problems, being content to accept the results worked out by the authorities engaged upon this subject. It will be sufficient for us to picture the atom as a large congregation of electrons all moving in regular orbits, one ring within another, and all moving round at a very great velocity. We must remember that all this energy is locked up within the atom. We need not say any longer that anything is



Electrical Attraction between Common Objects

If an ordinary flower vase be well dried and energetically rubbed with a silk handkerchief, the vase will attract any light body, such as a feather, towards it.

"as dead as a door-nail"; we picture every atom composing the nail to be anything but dead in the sense of being motionless.

But we have different kinds of atoms—those which form gold, and those which form the dirt upon our city streets. Are these atoms all made of the same stuff—electrons? We do believe so. Wherein then does one kind of atom differ from another? Simply in the number and arrangement of its electrons.

So far we have pictured a multitude of electrons or units of negative electricity congregated together to form an atom. If this were all, we should have an accumulated charge of negative electricity. Not only that, but all these individual units of negative electricity would repel one another, and our imaginary atom would be dissipated. There *must be* an equal quantity of positive electricity in the atom to produce an equilibrium or balance. We cannot picture an equal number of units of positive electricity, at least we have never found such things to exist. We have never found positive electricity apart from atoms of matter, whereas we have become familiar with the flying units of negative electricity in vacuum tubes. Indeed we really know far more about these electrons than we do about the atoms of matter.

As we cannot lay hands upon units of positive electricity apart from the atom, we must form some other reasonable picture of the positive electricity contained within the atom. One picture suggested is that of a uniform sphere of positive electricity throughout

which the electrons are distributed. The mathematician is willing to accept this idea as a working hypothesis, as he can thereby make reasonable deductions. The positive electricity attracts the electrons to the centre of the sphere while the electrons repel one another, and in so doing they tend towards leaving the sphere altogether. In other words, the electrons tend to fly away in all directions, but the positive electricity pulls them back, and an equilibrium is found

Not only has the mathematician been able to calculate a great variety of arrangements of electrons to produce possible atoms, but the experimentalists have demonstrated a great variety of arrangements by means of little floating magnets, or by small electrified bodies floating on water. Such experiments with different numbers of bodies show a great variety of arrangement, different patterns or designs being formed according to the number of bodies used in the experiment.

It will be of interest to follow a few experiments of this kind, and if one has any good means of *equally* magnetising a number of steel needles it will be of further interest to repeat the experiments. After the needles have been magnetised, each is fixed in a small cork, so that when the cork is floated on water the needle will hang downwards in the water in a vertical position. The needles are fixed so that either all their north poles or all their south poles are uppermost. If a number of such needles are thrown

into a basin of water, to represent the electrons in an atom, the needles will, of course, repel each other and practically try to escape from the basin by swimming to the edge, as shown in the first photograph in the frontispiece. This is just what the electrons would do in the atom, but for the controlling charge of the opposite or positive electricity drawing them to the centre. In our experiments we therefore represent this controlling charge by placing one pole of a magnet above the centre of the basin, as shown in the second photograph. If we have arranged the little needles with all their south poles uppermost, we place the north pole of the controlling magnet over the basin, as opposite poles attract one another.

If three needles be thrown into the water they arrange themselves so that they form the three corners of a triangle. Four needles take up their positions at the corners of a square, as shown in the second photograph, while five needles similarly form a pentagon or "five-sided square." When we throw in a sixth needle we see a very interesting phenomenon. The six needles do not attempt to form a hexagon or "six-sided square," but one needle goes to the centre and the other five arrange themselves in a pentagon as before. A seventh needle produces a phenomenon of even greater interest; one needle goes to the centre, while the other six arrange themselves in a ring at some distance from the central needle, as seen in the third photograph. As we proceed

adding needle after needle many interesting changes take place.

These, then, are the stable or equilibrium arrangements, and they help us to form useful pictures of the possible arrangements of electrons within the atom. Elaborate experiments made in this way have verified the arrangements suggested by purely mathematical calculations.

There is another point of great interest in connection with the mathematician's stable configurations. He finds that a great many of his different arrangements of electrons are very similar to each other. For instance, one of his possible atoms is constructed with one electron at its centre and six others around it, as in the third photograph, and as he proceeds tabulating all the possible stable arrangements he finds another to be just the same as the one mentioned, but with an additional ring of eleven electrons outside of it, as seen in the fourth photograph. Then further on in his table he finds this larger arrangement with still a further additional ring of fifteen electrons outside of it. Now if atoms are really constructed upon this principle, we should expect to find some similarity between the behaviours of certain different atoms in nature. We should find certain groups of the atoms having family likenesses, and therefore possessing similar properties. We do actually find this in nature, indeed this fact was recognised long before any attempt had been made to dissect the atoms.

In our school-days we became aware how very

similar potassium and sodium are to each other. They are both very soft metals, which may be cut quite easily with an ordinary penknife. They have both a bright silver-like lustre when cut, but this soon tarnishes or oxidises. They both possess the remarkable property that when thrown upon a damp surface they will blaze into flame. Potassium is the more energetic in this respect ; it will even catch fire when thrown into a basin of water, whereas sodium, under the same circumstances, will also set up decomposition of the water and evolve considerable heat, but will not ignite. It does ignite, however, when merely placed upon a damp surface. The chemist could tell us of further properties which are common to both potassium and sodium.

The chemist could also show us a third elementary substance called *lithium*, which is of the same silvery-white appearance, and which is also a soft metal, though not so soft as potassium and sodium. We could not get lithium to catch fire on a damp surface, but we should find that it possessed the same property of decomposing water and evolving heat, though not in sufficient degree to display the energetic combustion that its two other relatives can.

Here we have a family group of three elementary substances, and this is not an isolated case. We find that all the other elements may be grouped into little family parties in a similar fashion. The most interesting point in this connection is that we do not require to pick out the members of a family group by examining

their properties. If we know the atomic weights[1] of the different elements we can divide them into their respective families.

In 1863 John Newlands pointed out, in a letter to the *Chemical News*, that if the elements were arranged in the order of their atomic weights, beginning with the highest and going down to the lowest—just like the keys of a piano—those elements belonging to the same family occurred at regular intervals in the scale. Picturing the keyboard we select the note representing potassium, and we find that sodium is exactly an octave above potassium, while an octave above that again brings us to lithium. If we take the octaves below potassium we find first of all the element *rubidium*, and then another octave lower *cæsium*. Although the ordinary man is not familiar with these substances, he learns from the chemist that they possess a striking family resemblance to potassium, sodium, and lithium.

The members of the other family groups were found to occupy similar positions to each other. Later on these octaves of Newlands were further elaborated by the famous Russian chemist Mendeléeff, and also by the great German chemist Meyer, and what is known as the *periodic law* was established.

For our present purpose we need not trouble with the full meaning of the periodic law. It means, in

[1] The atomic weights are the proportions by weight in which the various elementary substances unite together. The atom of hydrogen is taken as the unit; hydrogen being the lightest of the elements.

short, that if we know the weight of an atom of any element, we may know its properties. It is of great interest to note, however, that Mendeléeff placed such confidence in this law, that he boldly prophesied the existence of three other elements which had never been discovered. He found three empty spaces in his periodic table, which must be filled if the law was perfect. He could tell what families these missing elements should belong to, and so he boldly predicted the chemical properties which those elements should be found to possess when, at some future time, they might be discovered. It is interesting to know that Mendeléeff lived to see the discovery of the three missing elements, and to witness the fulfilment of his predictions. One by one the missing substances were brought to light, and each possessed the properties predicted for it, or as our American cousins would say, they exactly "filled the bill."

This periodic law was established long before the Cambridge physicists commenced their calculations as to the possible arrangements of the electrons within the different atoms. Professor J. J. Thomson now suggests that the atomic weight of an element is proportional to the number of electrons contained in its atom. We must remember, however, that each congregation of a certain number has a definite form of arrangement. It is not at all analogous to having one bag of sixty-seven marbles and another of sixty-eight. We not only picture the electrons arranged in definite designs of rings within rings, but we see a complete

system of revolving planets; a perpetual and regular orbital motion.

The mathematician informs us that certain configurations are not very stable, and, indeed, that some are just on the verge of instability. For instance, one arrangement has just sufficient electrons in the centre to hold the outer ring together. If the outer ring is disturbed by any external source, some of the electrons in the outer ring may fail to return to their former positions. The electrons are all flying round at a great pace, so that any of them losing hold of their system will fly off from it. These detached electrons will immediately find a new home in a neighbouring atom whose system is such that it can readily accept them. We therefore picture a continual interchange of a small number of detachable electrons between the atoms. Our simplest plan may be to picture these detachable atoms as being comets outside of the regular stable orbits. We shall see later, however, that there are abnormal cases of instability where the electrons fly off from the regular orbits and are shot into the surrounding air with great velocity, causing those wonderful phenomena associated with *radium* in particular. Here we have the atom really breaking up, which is quite a different thing from the friendly exchange of detachable electrons.

What difference does this friendly exchange of a few detachable electrons make to the atom? It means that when an atom loses one or more electrons it no

longer possesses a perfect electric balance. Some of its negative charge has fled with the escaped electrons while the positive electric sphere has remained constant. The atom which has lost electrons consequently becomes a positively charged body, for the positive charge will preponderate over the reduced negative charge; we call such atoms *electro-positive,* and the more electrons the atom loses the more electro-positive does it become. On the other hand, an atom which has gained some electrons has necessarily added to its negative charge, which then preponderates over its constant positive sphere, so that such atoms become *electro-negative,* and the more electrons gained the more electro-negative does the atom become. We should therefore find in nature some electro-positive atoms and some electro-negative ones; we should also find different degrees of these conditions. These very phenomena are well known to the chemist of to-day; he finds some atoms strongly electro-negative under certain conditions, but less so under other conditions. He finds similar degrees of variation in electro-positive atoms. But we must remember that the interchange of electrons with which we are dealing does not alter the nature of the atom. A hydrogen atom is always a hydrogen atom whether it happens to be more or less electro-positive. If we could alter the number of electrons in an atom to any degree we desired, we could turn lead into gold, and mud into diamonds. But we cannot perform such transmutations, for neither the chemist nor the physicist can break down

the stable configurations of the atoms. We have evidence, however, that Nature is a genuine alchemist, and that she is carrying on actual transmutations of which we were quite ignorant until the phenomenon of radio-activity was discovered; but, as already indicated, we shall consider this later.

In the preceding chapter we saw that *chemical* union simply meant *electrical* union, and that an electro-positive atom joined hands with an electro-negative atom. We are better able to appreciate now the reason why one strongly electro-negative atom of oxygen can lay hold of two weaker electro-positive atoms of hydrogen; the negative charge of the oxygen atom requires the positive charge of two hydrogen atoms to produce an electrical equilibrium. The result is a neutral molecule of water.

Another way of looking at the matter is to picture the oxygen atom as being capable of accepting two additional electrons when brought close to any atom or atoms which are capable of losing such electrons. A single hydrogen atom is only capable of losing one electron, but two hydrogen atoms acting together can give the oxygen atom two electrons. These three atoms therefore become electrically united, or we may speak of it also as a chemical union.

Some reader may wonder why a mass of any element does not exhibit an electric charge. If the hydrogen atoms are electro-positive, why does the gas in bulk not exhibit a positive charge? When we speak of the hydrogen atoms being electro-positive,

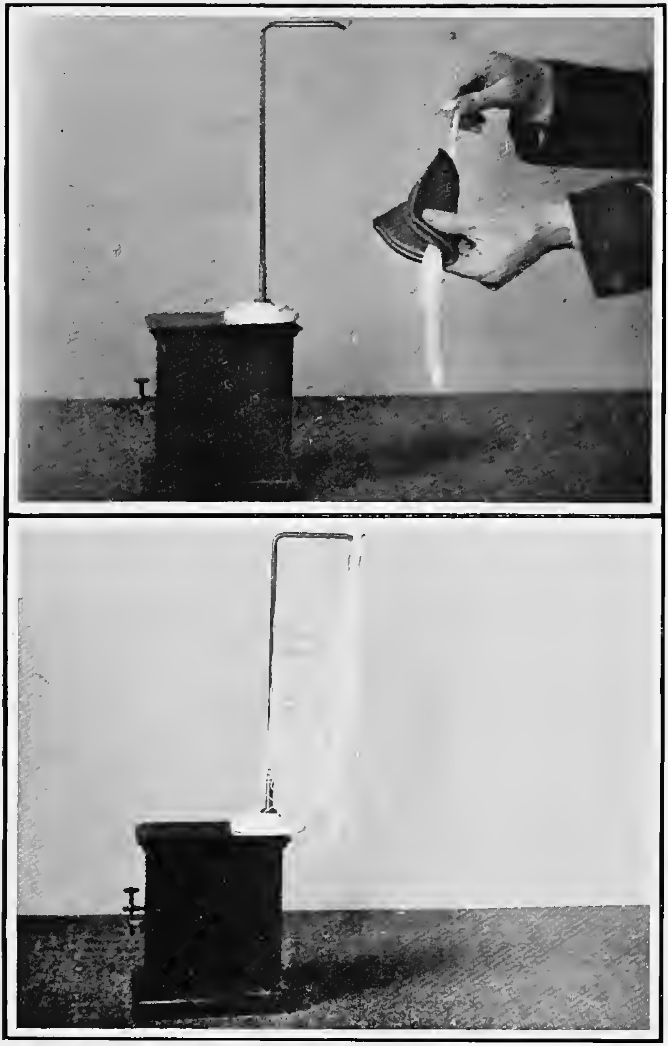
what we really mean is, that they are capable of losing an electron and thus becoming electro-positive. Left alone, the hydrogen atoms are electrically neutral, but as soon as they come within very close range of oxygen atoms, two of the former each hand over an electron to an oxygen atom, and thus upset the electric equilibrium. It is this interchange of electrons which produces the electrical charge of the atoms and causes them to attract one another and form simple or compound molecules.

It will be remembered that, in a former chapter, when we were dealing with chemical union, there appeared to be a difficulty if we considered the union to be due to the attraction of opposite electric charges in the atoms. Not only did electro-positive and electro-negative atoms join hands—as in the case of an electro-positive atom of sodium uniting with an electro-negative atom of chlorine, to form that useful substance which we call common table-salt—but an atom sometimes acted as though it were electro-positive, and at other times electro-negative. For instance, the compound *marsh-gas* (fire-damp) is composed of one atom of carbon and four atoms of hydrogen, both of which are electro-positive to oxygen. We must therefore understand that the terms electro-positive and electro-negative are merely relative. Carbon may be electro-positive to oxygen and yet electro-negative to hydrogen.

It is difficult to find a suitable analogy to illustrate the foregoing fact. But perhaps it will be of some assistance if we picture the atoms arranged in a scale

so that any atom may readily give up some of its electrons to any other atom which happens to be below it in the scale. We picture the atom which is capable of accepting electrons to be electro-negative, for it will then have surplus electrons; the atom losing electrons will represent the electro-positive atom. We picture a certain kind of atom giving electrons to another atom lower down in the scale, and we say the former is electro-positive; but at the same time we see that this same electro-positive atom is able to accept electrons from another kind of atom which is still higher in the scale, and in this case it is no longer electro-positive, but becomes electro-negative.

While the foregoing analogy may be of some assistance, it is not complete. For instance, it does not take into account the fact that two atoms of the same element—say oxygen—unite together to form a molecule of oxygen. Our analogy would suppose that because both atoms are on the same level on the scale neither could throw electrons at the other. The physicist can adduce reasons, however, for supposing that when two atoms of the same element come so near together that the revolving electrons in the one atom can exert force upon the revolving electrons in the other, there is an interchange of electrons which causes one of the atoms to become electro-negative to the other. In this way we may still picture two atoms of oxygen as being electrically united to form a molecule of oxygen.



Electrical Repulsion

If a tassel of ordinary sewing silk be briskly rubbed with a rubber tobacco pouch, the silk threads will become similarly electrified and will therefore repel each other, as seen in the lower photograph. The electrified threads will attract any unelectrified body, so that those threads near the upright stand cling to it.

Now we have formed a mental picture of the construction of the atom. We see the electrons or units of negative electricity incessantly whirling round in regular orbits, and prevented from repelling each other by the constant sphere of positive electricity within which the revolving system of electrons is enclosed. We picture certain stable configurations being due to the number of electrons contained within the atom. It is these different configurations which give us the different properties of atoms, or, in other words, constitute the different elementary atoms. One configuration we have called the atom of sodium. We can never hope to see these atoms, even with the most powerful microscopes, but when a vast multitude of many millions of these atoms congregate together we see a lump of matter which we call sodium. It is a soft metal, with the peculiar property of catching fire when placed on a damp surface, as already described.

Another configuration of electrons we call an atom of chlorine; it differs from the other in the number of electrons and the resulting configuration. A vast congregation of atoms of this kind produce a gas which we recognise as chlorine. Its properties are well known to all those who have studied chemistry. But, marvellous to relate, when we have a great congregation of these very same atoms—chlorine and sodium—wedded together in couples, we have no longer a gas and a metal, but a totally different substance which we use at the dinner-table to season our

food. One might feel inclined to say that salt is made out of a gas and a metal, but that is really not a correct idea. Salt is made out of two different kinds of atoms —one of which goes to form a gas and the other a metal —but these atoms themselves which go to form matter are neither gas nor metal; they are revolving systems of electrons—pure electricity.

In short, we picture all matter, whether it be a valuable diamond or a nauseating gas, to be composed of atoms, and these atoms are nothing more or less than little spheres of positive electricity within which tiny units of negative electricity are constantly revolving in certain definite orbits, the one atom only differing from another in the number and arrangement of its negative units or electrons.[1]

If this electron theory be true—then all matter is made solely of electricity. A little fellow asked me if there was any electricity in him, and he thought it a huge joke when I said that he was made of electricity. Of course, we must keep in mind that this is only a *theory*, but the idea that our Earth is going round the Sun was only a theory till we found so many facts which fitted in with the theory that all thinking men were willing to accept it as a fact. The electron theory finds many facts to support it; the electron has actually been separated from the atom, as in Crookes' vacuum tubes, where we produce a real stream of pure electrons. But we have not been able to separate the

[1] Whatever the sphere of positive electricity may turn out to be, there is no doubt that it must vary also with the number of electrons.

positive electricity in the same way, so the positive sphere of electricity, in which the real electrons revolve, is at present purely hypothetical.

There are other possible theories regarding the construction of the atom, but the mathematics of this theory which we have been considering have been so beautifully worked out by Professor J. J. Thomson, of Cambridge, that this theory seems to stand head and shoulders above all others. No one will suppose, however, that this theory, when completed, is to be the final word of Science. Science must ever live and progress from one step to another.

If matter is composed of negative electricity and positive electricity, our next question will naturally be —What is Electricity?

CHAPTER V

WHAT IS ELECTRICITY?

The nature of electricity—Franklin's original idea—Departure from and return to Franklin's ideas—Positive and negative electricities—A haphazard guess—What occurs when a glass rod is rubbed with a piece of silk cloth—The meaning of a discharge of electricity—What constitutes an electric current—Volta's original discovery explained—How the current passes along a wire—An analogy—The cause of electrical resistance—How we increase electrical pressure —Low-pressure currents—Insulators—Summary

OUR thoughts regarding the nature of electricity are very different from what they were only a few years ago. The onlooker might say that our ideas in this connection are retrograde, for it is a fact that our present conceptions of electrical matters are not at all unlike the very first ideas of Benjamin Franklin. Franklin is perhaps best known to the general reader by his historical experiments in drawing electricity from thunder-clouds by means of flying-kites. But Franklin was a very distinguished American statesman as well as a great natural philosopher.

In the early days of electricity, about the year 1750, Franklin suggested that electricity was a subtle fluid pervading all matter. As time went on, the scientists began to think that this was far too materialistic an idea of electricity. If one looks back over the literature

concerning electricity, published between the date of Franklin's theory and the advent of the present electron theory, it is most apparent that writers considered electricity to be much more mysterious in nature than Benjamin Franklin did. Indeed it is clear that the writers ultimately endeavoured to fight shy of the word *electricity* altogether, preferring to speak only of its manifestations—the electric current, electrification, and so on. To-day the electron theory brings us back to much more materialistic ideas; we feel quite familiar already with the *atom* or *unit* of negative electricity. We might speak of atoms of electricity, but as the word *atom* has such a definite idea of matter attached to it, the word *unit* seems the better. Even the word *unit* may convey too much of a purely mathematical idea to some, so that we are quite pleased to find that there has been a satisfactory christening, that the unit of negative electricity is known as an "electron." As regards the atom or unit of positive electricity we are more ignorant.

In the light of present-day knowledge we see that Franklin's *one-fluid theory* was really a very remarkable forecast. Franklin said "the particles of this fluid repel each other." That is exactly what our modern electrons or negative particles do; they repel each other because like electricities are repellent. Franklin said that the two different kinds of electrification which had been observed—that produced by a glass rod and that produced by sealing-wax—were simply due to an excess and a deficiency of the fluid. It was

in this connection that the words *positive* and *negative* electricity were introduced. A positively charged body was supposed to possess a surplus of the fluid, while a negatively charged body was supposed to have a deficiency of the same fluid. Although the two different kinds of electrification could be demonstrated by simple experiments, there was nothing whatever to indicate which body contained the excess and which had the deficiency. There was nothing for it but to make a haphazard guess as to which was which. Glass rods were given the credit of possessing a surplus quantity of the fluid particles when "excited," and were said then to be positively electrified. We still speak of a glass rod being positively electrified when it has been rubbed with a piece of silk, but we do not suppose that it contains a surplus of electrons; we picture exactly the reverse. We continue the old terminology to save any confusion by a change, and it will be observed from the preceding chapters that the introduction of the idea of a constant positive sphere of electricity in the atom prevents any real confusion. The atoms of the glass rod have lost electrons during the rubbing process, so that the constant positive spheres preponderate. This idea enables us still to think of the glass rod as being positively electrified. It is the negatively charged body which has an excess of electrons, but that too seems quite natural, because the addition of small negative charges causes the total negative charge to preponderate over the constant positive charge.

It may be of interest to form a graphic picture of what happens when we rub a glass rod with a piece of silk cloth. Electrons leave the glass rod and attach themselves to the silk. The silk having gained a multitude of little negative charges becomes negatively electrified, while the atoms of the glass rod, having lost these same negative units, show a preponderance of their positive charges. But why was the flow of electrons not the other way about? Why did electrons not go from the silk to the glass?

Referring to the analogy suggested at the close of the preceding chapter, we picture the atoms in the glass to be higher in the scale and able to lose electrons to the atoms in the silk; this happens when the atoms are brought as near to one another as possible in the process of rubbing. But if we select some substance whose atoms are lower down in the scale than the silk—say sealing-wax—then we can get the silk to lose electrons to the sealing-wax. In this case the silk becomes positively electrified, having lost some electrons.

It will be noticed that the electrical condition of the silk depends entirely upon which substance it is rubbed against. Its position is relative to the others, but we must not think from this that the terms *positive* and *negative* electrifications are relative conditions. We must firmly fix in our minds that if a body is positively electrified it means that it has lost electrons, and if it is negatively electrified it means that it has gained electrons. These are definite conditions, and not degrees

of one condition. We have different degrees of positive electrification and of negative electrification, but the two conditions positive and negative are exactly the reverse of each other; the one being a deficiency of electrons below the normal condition of the substance, while the other condition is an excess of electrons over the normal condition. We have, therefore, a graphic picture of the silk cloth gaining electrons when rubbed against the glass rod, and, on the other hand, losing electrons when rubbed against the sealing-wax.

I am well aware of the difficulty which the average layman has with the terms *positive* and *negative* electricities. When dealing with the practical applications of electricity in former works addressed to the general reader, I have avoided the use of these terms, but it will be clear that in dealing with the science of electricity it is an absolute necessity to speak of positive and negative electricities, unless we fall back upon the older terminology of vitreous and resinous electricities. I believe the late Lord Kelvin would have been pleased to see this older terminology adopted had it been possible to make such a drastic change. The repeated use of the terms *positive* and *negative*, however, dispels any feelings of mystery, and I trust that with what has already been said in this and the foregoing chapters the meaning of the terms will remain perfectly clear.

It will be of interest to form a definite mental picture of what we mean by a discharge of electricity. Perhaps the simplest way will be to think of the discharge

which takes place in a highly exhausted vacuum tube. Electrons are shot off from the cathode or negatively charged terminal. An electrical discharge is therefore a discharge of electrons. It is always the body with the excess of electrons, or in other words, the negatively charged body, which discharges the electrons. The discharge is really from the negative to the positive.

It will be remembered that the stream of flying electrons in the Crookes' tube behaved exactly like a conductor carrying an electric current. The stream was deflected by an ordinary magnet, just in the same way as a wire carrying an electric current is deflected by a magnet. Are we to understand from this that moving electrons constitute an electric current? That is our creed. We believe an *electric* current to be nothing more or less than an *electron* current.

We can prove by experiment that electrified spheres in motion produce all the properties of an electric current. We believe all electric currents to be electrons in locomotion. What happens then when an electric current flows along a copper wire? We picture the copper atoms very closely packed together, so close that we cannot compress the metal perceptibly. It will be evident that the nearer the atoms are to one another the easier will it be for one atom to hand on a detachable electron to its neighbouring atom. We picture roaming electrons within the metal. If we can only apply some external force to cause a flow of electrons in one direction from atom to atom, we shall

have an electric current. We have several convenient means of setting and maintaining the electrons in motion.

More than a century has passed since Professor Volta, of Pavia (Italy), discovered that when a piece of zinc touches a piece of copper the zinc becomes very slightly positively electrified and the copper correspondingly negative. In the light of the electron theory we should say that when the zinc and copper come into contact some electrons escape from the zinc atoms and find a home on the copper atoms. We may imagine that there is a natural desire on the part of the zinc atoms to give their spare electrons to the copper atoms, but they cannot do so until the atoms are brought comparatively near to one another by the lumps of metal being placed in contact. The zinc atoms cease giving up electrons as soon as the copper atoms have accumulated sufficient electrons to balance matters between them.

It may be remarked in passing that zinc is always very willing to give up a large quantity of detachable electrons. The late Professor Hertz, of Carlsruhe (Germany), who laid the foundations upon which wireless telegraphy has been worked out, discovered and demonstrated the fact that zinc will part with electrons with very slight encouragement to do so. He took a plate of zinc and caused the light of an arc lamp, or other source of ultra-violet light,[1] to fall upon

[1] Ultra-violet light simply means light which is beyond the violet end of the spectrum. Invisible rays which have an energetic chemical effect, as will be explained later.

it. The zinc plate showed signs of becoming positively electrified. The plate was previously connected to a sensitive electrometer which would indicate any change of electrical condition in the zinc. The fact that the plate now exhibited a positive charge proved that electrons had escaped, these having been set free by the bombardment of the ultra-violet light. It is an interesting fact that when air is blown along the plate the expelled electrons are carried away, attached to the molecules of air, and a further expulsion of electrons from the plate is more easily carried on until the zinc plate shows a considerable charge of positive electricity. For the sake of those who know something of electrical measurements, I may mention that this charge sometimes reaches as high a pressure as thirty volts.

We have seen that a piece of zinc will give up its spare electrons whenever it has an opportunity of doing so, but in the cases which we have been considering, the atoms have remained fixed in their original positions and have merely given off a spare electron or two. Suppose that we give the atoms an opportunity of moving away from their anchorage, we shall see how much more willing they are to give away electrons. When a piece of zinc is placed in a solution capable of dissolving it, some atoms are freed from the solid metal and these atoms very quickly part with electrons, indeed they seem only too willing to leave their detachable electrons behind them in the solid metal and to escape without them into the solution.

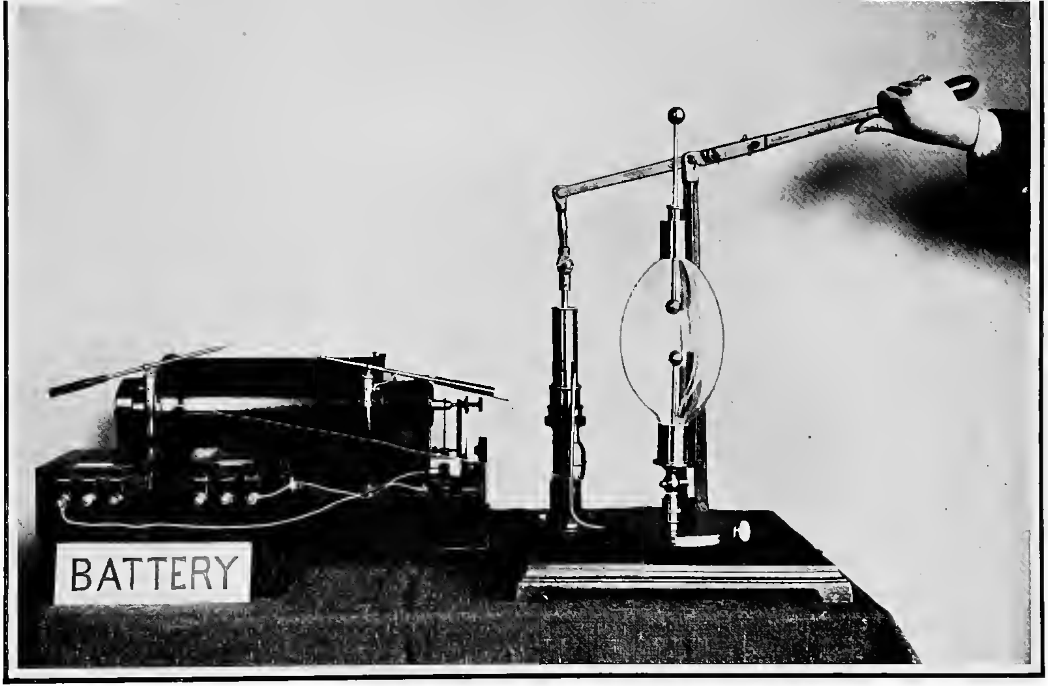
wire connecting the zinc to the copper; we have a continuous electric current in the wire. We may make the wire long enough to reach an electric bell in an adjoining room and then come back to the copper, so that the electric current must pass through the electric bell before it can get from the zinc to the copper.[1]

I have endeavoured to keep up the idea of the zinc atoms giving electrons to the copper atoms, and we may still do so if we picture the copper wire as being an extension of the copper plate. We might bend the copper plate so that its outer end touched the top of the zinc plate, but this would not be so convenient as making a connection with a piece of flexible wire. This wire need not be of copper; it might be gold, silver, or iron. It is better, therefore, that we should picture the atoms handing along the detachable electrons. It may be of service to repeat an analogy which I suggested in "Electricity of To-day."

There is a game which I have seen children play, and which may serve as an analogy of electrical conduction in metals. The children stand in a long row, and at one end of the row is placed a heap of objects —say, a large number of pennies. At a given signal the children pass the coins along from one to the other till they reach the other end of the row, where they are deposited in a heap. No child is allowed to accept a coin till he or she has passed on the previous one;

[1] We cannot stop to consider the action of the electric current in the bell; I have already explained the practical application in "Electricity of To-day."

This behaviour on the part of the escaping atoms completely alters the former condition of things. When the zinc plate was merely put in contact with a piece of copper the zinc atoms were able to give off a few electrons to the neighbouring copper atoms. But when the zinc is placed in a dissolving solution, the atoms escaping from the zinc leave their detachable electrons behind them so that the zinc plate soon accumulates a surplus of electrons, and therefore it will be all the better able to give electrons to the copper atoms. We picture a piece of solid copper placed in the solution beside the zinc but not touching it. The zinc is accumulating electrons, so we form a bridge by which the surplus electrons can make their way to the copper. This we do when we join the outer end of the zinc by a piece of copper wire to the outer end of the copper. We may imagine the zinc atoms as having another opportunity of giving electrons to the copper atoms, and as the zinc atoms have accumulated a large quantity of detachable electrons formerly belonging to those atoms which have escaped into the liquid, the transfer of electrons between the zinc and the copper is therefore much more energetic than was the case when zinc and copper were merely placed in contact. It will be apparent that as long as we keep up the chemical action, or in other words, as long as more atoms keep escaping into the liquid and leaving spare electrons, the remaining atoms are able to keep up the supply. We have a constant stream of electrons along the



METHOD OF PRODUCING A STREAM OF ELECTRONS

To the left may be seen a battery and induction coil, which cause an electrical discharge to take place between the two brass rods within the egg-shaped globe. This globe is attached to an air pump, and when the air is exhausted from the globe, a constant stream of electrons passes between the rods, as explained in the text.

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the action has to be simultaneous along the line. A second row of the same number of children stands parallel to the first row, and these are also provided with an exactly similar number of pennies. The game is, of course, a battle royal between the two parallel rows as to which row can transmit the whole of the coins in this fashion from the one end of their line to the other in the shortest space of time. Only one row of children concerns us in our analogy, and we picture the little ones as representing the atoms in a length of metal wire. Each atom passes on an electron to its neighbour, and accepts another electron from the neighbour on its other side. For the sake of analogy we start the game with each child having one coin in his or her hand, so that the moment the signal is given, representing the closing of the electric circuit, a complete transfer commences simultaneously all along the line. Instead of having a heap of coins at one end, we might arrange the children in a circle and give them one coin each, so that the coins would pass round and round the circle. This is what we understand by a complete electric circuit; a battery or dynamo acting as a pump in the circuit. We may break the complete circuit, and then there can be no passing on of electrons.

The first arrangement of the children's game, in which we had the children standing in a row, is somewhat analogous to an earth circuit in electrical affairs. The first child kept picking up coins, passing them along, and the last child deposited the coins in a heap

as they were received. We imagine, therefore, the first atom at one end of the wire, which is dipping into the Earth, to be helping itself to electrons one at a time, passing them along, and the last atom at the other end of the wire depositing these electrons in the Earth. There is, of course, a battery or a dynamo again acting as a pump, and we do not have a simple row of atoms, but a myriad of atoms acting simultaneously.

As the electrons pass along from one atom to another they meet with some obstruction. Perhaps the matter may be simplified by the following analogy. In our schooldays we would sometimes form a circle of boys on the cricket-field, and amuse ourselves by passing the ball quickly from one to another round the circle. It is obvious that the ball will meet with a sudden obstruction at each forward step. It is this kind of obstruction in the passage of the electrons that we call *electrical resistance*. It is not difficult to picture one set of cricketers much more expert in passing the ball round the circle than another set might be, so that the ball would really pass more easily round the first circle. In the same way we find the atoms of some metals are able to pass on the electrons much better than the atoms of other metals are able to. We speak, therefore, of good electrical conductors and of poor conductors or *insulators*. All metals are really good conductors, although some are much inferior in this capacity to others. For instance, the electrons meet with six times more resistance in passing along

an iron wire than they do in a copper wire of the same size. If we wish an iron wire to carry the electron current from one town to another, we must provide a larger number of atoms to do the carrying, than we should require if we used a copper wire. Hence an iron telegraph wire is much thicker than a copper one. The difference between the sizes of the two wires, when suspended on telegraph poles, is very noticeable. The general practice, until recently, was to use iron wires for telegraph lines, whereas the telephone companies have always used copper wires. As one walks along a country road one can easily pick out the heavier iron wires of the telegraph lines.

If we picture a battery acting as a pump and driving the electrons along the wire joining the zinc plate to the copper plate, it will be obvious that the longer we make this connecting bridge the more resistance will the electrons encounter. If we have a long telegraph line acting as a bridge for the electrons, we must apply greater pressure than can be obtained by a single chemical cell such as we have been considering. We may couple a number of such cells together, and in this way increase the *pressure*. There are two ways of coupling such cells together. We might connect the zinc of one cell to the zinc of the next cell, and the copper of that cell to the copper of the next cell, then the zinc of the third cell to the zinc of the fourth cell, and so on. But this would not increase the *pressure*. The combined zincs could certainly provide a greater quantity of electrons, and we could have a larger

current, but the increased army of electrons would have no greater stimulus to force their detachable electrons away. Each zinc plate would simply add its normal contribution to the combined flow. If, however, we connect the zinc of one cell to the copper of the next cell, and the zinc of the second cell to the copper in the third cell, and so on, zinc to copper, zinc to copper, we shall have a totally different result. We picture the first zinc passing on its accumulation of electrons along the wire bridge to the copper in the second cell. This copper passes on these electrons through the liquid to the zinc standing in the same cell, whereupon this zinc has not only its own accumulation of electrons but as many more which have been passed on to it from the first cell. The second cell has therefore a greater *pressure* of electrons accumulated on its zinc, and as we add cell to cell in this fashion we go on increasing the pressure along the connecting bridges. In the first case, in which we say the cells are connected *in parallel*, we have a low pressure, and we therefore require a correspondingly thick wire to carry a large current. A thinner wire would carry the same current when we connect the cells *in series*, as in the second case. In the same way we can do with a smaller bore of water-pipe if we increase the pressure of the water. There is another point of interest here. If we increase the water-pressure to any great extent we must increase the thickness of the metal pipe, or the water may force an escape. In the same way we must increase the

insulation of a wire carrying a high-pressure electric current.

In the case of a wire carrying a high-pressure electric current, it so happens that the atmosphere makes a very good insulator, but we have to see that the supports of the wires are better insulators than are necessary for wires carrying a low-pressure current. Glass, vulcanite, and porcelain make good insulators; electrons meet with a tremendous resistance in trying to pass through these substances. For all practical purposes we consider that they completely block the way of the electrons. If the electrons are forced through them with an immense pressure, such as may be obtained by a very large induction coil, the passage of the electrons may rupture the glass.

At the Royal Institution (London) I have seen a block of glass, three inches thick, which was fractured by the electrical discharge of a large induction coil. The glass was pierced right through, and it was no mere pin-hole, but looked exactly as though some machine-tool had been forced through and left a hole. This is what takes place in quartz glass; when flint glass is used there is a complete fracture of the block. I remember seeing Sir Oliver Lodge fracture a thick glass tumbler, by an electrical discharge, in the late Lord Kelvin's laboratory.

In the earlier part of this chapter we have considered the action of a chemical cell, in which the elements were a plate of zinc and a plate of copper, and while this is not a common form of cell at the

present day, it gives us the general principle underlying the action of all batteries. A very common kind of "battery," in general use to-day, is a piece of zinc and a piece of carbon immersed in a dilute solution of sal-ammoniac. Our present purpose is not to deal with the practical arrangements of different cells, but merely to consider the scientific ideas concerning the action of cells.

To sum up, we have seen that a charge of electricity simply means an accumulation of electrons on one body, and a corresponding deficiency on another body. We may have wondered, at some time or other, that when two bodies are rubbed together the charge on the one body is always exactly equal and opposite to the charge on the other body. The matter is very simple; the result cannot be otherwise. The one body has lost a certain amount of electrons, and the other body has gained the very same electrons. A discharge of electricity is simply a discharge of electrons from one body to another.

We have also seen that an electric current is merely a current of electrons, and unfortunately we have been in the habit of picturing this current flowing in the opposite direction to that in which the electron theory shows the real current to flow. The flow of electrons is from the point at which there is an accumulation, or in other words, from the negative terminal to the point of deficiency, which is the positive terminal. We have always considered the current flowing from positive to negative, but our

mistake has been due to the early electricians attaching the terms *positive* and *negative* to the wrong conditions, as already explained. However, as long as we keep in mind that it is a current of negative electricity—or electrons—with which we are dealing, there should be no cause for confusion.

If the electron theory be true, and as far as it takes us it does seem to be true, then we have a fairly clear idea of the meaning of an electric charge, and of an electric current, but we have not answered the question—What is Electricity? Until we answer this question we cannot say what the electron is; at present we merely know it to be a negative charge of electricity.

It may be well to state clearly that no one knows what electricity is, but we shall proceed to see upon what other phenomena the electron theory sheds new light. Before proceeding further, however, it may simplify matters if we seek to become familiar with the mysterious æther of space.

CHAPTER VI

WHAT IS THE ÆTHER?

The spelling of the word æther—The existence of an all-pervading medium — Wave-disturbances in water, air, and æther — Diversity of waves in æther—Light and darkness—Heat does not travel from the Sun—What travels?—Transformations—Invention of the idea of an æther—Its first reception—There must be a medium—Demonstration of its existence—Not ordinary matter—Mendeléeff's idea. A possible theory of the future—Analysing æther waves—X-rays—"Wireless" waves—Velocity of æther waves—Constant velocities—Fields in the æther

WHENEVER one picks up any book of modern science, which treats of the physical side of things, one is sure to find continual reference to the *æther* of space. A very natural question arises as to what this æther is.

It is more common to spell this word *ether*, but as we have a chemical combination of ordinary matter called ether, it would seem wiser to spell the word *æther* when it refers to the space-filling medium. It may be that people fight shy of the latter spelling because of the trouble in writing a diphthong, or it may be that there is really no reasonable excuse for any one confusing this space-pervading "something" with ordinary matter. I do not suppose that any one is going to think of this universal medium as being the same as that ether which is made from alcohol, and is now so largely used

in place of chloroform. Nevertheless the word æther seems to take us farther away from ideas of ordinary matter. I shall, therefore, use the latter spelling, although when one becomes familiar with the idea of the all-pervading medium it matters very little which spelling is used. It goes without saying that the æther is not any form of ordinary matter, but let us first of all try to realise the existence of the æther.

The idea of an all-pervading medium is not a wild dream or mere speculation. If we study observed facts we are forced to admit the reality of the æther. The scientist is as sure of the existence of the æther as he is of his own existence. It would be quite unreasonable, despite all the logic of John Stuart Mill, to imagine one body acting upon another unless there be some intervening medium between the two bodies. To take a simple illustration, we may imagine two men swimming about in a quiet pool of water. One of the men might set up a series of waves in the water, so that these would travel to his companion and attract his attention. Observe that nothing really passed from the one man to the other ; the intervening medium was disturbed, and in this way the one body acted upon the other, though at some distance from it. The water did not travel from one man to the other ; it was merely the wave-disturbance that travelled.

To take another illustration, we may imagine a church-bell to be tolling in a distant steeple on a quiet morning. The bell, though fixed at a certain place, is acting upon the hearing apparatus of people

at a considerable distance. There is nothing passing out from the bell to the distant audience. The bell is merely disturbing the intervening medium—the air—and in turn the vibrating air disturbs the ear-drums of the listeners. Again it is merely the wave-disturbance which has travelled.

One other illustration brings us to the point we wish to realise. We imagine a dark, wild winter's night, and we see a great lighthouse flashing out its light to give warning to approaching steamers. The lighthouse lamp acts upon the eyes of the far-distant sailor. The fact is so commonplace that it seems almost out of place to refer to it, but it is none the less wonderful. Nothing has travelled across the intervening space but a wave-disturbance in the intervening medium. What intervening medium? Certainly not the air, for a gale of fifty miles an hour is driving past the lighthouse, and yet the *waves of light* have not been disturbed in any way. Sound waves in the air would certainly have been affected by the flying wind. There *must be* some other medium other than the air, and it is this medium which has been christened the *æther.*

We picture the lighthouse lamp disturbing the surrounding æther, and setting up a series of waves in it. These waves travel out to the distant sailor and produce certain sensations in his brain by acting upon his eyes. In every case we can imagine, one body acts upon another distant body by disturbing some intervening medium.

It is a strange fact that some æther waves produce totally different results from others. The far-distant Sun sets up certain æther waves which fall upon our eyes and affect our sensory organ of vision. The Sun also sets up another kind[1] of æther wave which, falling upon us, heats our bodies, and all other objects upon which the waves fall. The æther transmits both these disturbances at the one time; *light* waves and *heat* waves.

Not only has the æther this twofold duty to perform, but it must also carry the waves set up by a wireless telegraph-transmitter. These *electric* waves are very large disturbances in the æther, and it is possible to communicate with ships at sea, provided the ship has a wireless receiver which is sensitive to these æther waves. All that we desire to notice at present is the different results produced by æther waves.

We must keep in mind the fact that light and heat do not travel to us from the Sun, but merely æther waves which produce these results. It is unfortunate that these æther waves were ever called *light* and *heat*, as this terminology certainly leads to confusion. We have tried to mend matters a little by calling the æther waves, which produce heat, *radiant heat*, but we have made no attempt to rechristen the æther waves which produce light; we merely call them *light*. This leads us into the use of some curious expressions; for many

[1] We shall see later that all æther waves are of the same nature, but differ in their wave-lengths.

of these *light* waves do not affect our eyes, so that we speak of these particular waves as *invisible* light. On the other hand, we naturally associate light with our sensation of vision.

Suppose we have an ordinary photographic camera set up in a studio, and we have the room brightly lighted by an electric arc lamp. We have a specially constructed screen or shutter in front of the lens, and this screen cuts off all the ordinary or visible light. When the visitor puts his head under the focusing cloth to examine the picture, he of course sees nothing upon the ground glass; all is totally dark within the camera. Nevertheless we are going to take a photograph with this "total darkness." A gentleman sits in the orthodox manner to have his photograph taken, and although there is absolutely no trace of an image upon the focusing screen, we replace it with an ordinary photographic plate. After a five minutes' exposure the plate is developed, and a portrait is produced, the result being very good considering the length of time the sitter had to remain in one position (see illustration facing page 186). It is obvious that some invisible light did enter the camera, and that although this light makes no impression whatever upon our sensory organ of vision, it does affect the chemicals upon a photographic plate in the same way as ordinary light. We speak of this invisible light as ultra-violet light, signifying that it is beyond the violet end of the spectrum when light is analysed by a glass prism.

My present purpose is to point out that all light is invisible, in the sense that it cannot be seen. Some years ago there was a very interesting book published under the title, "Light Visible and Invisible," but we attach a special meaning to the adjectives. We simply mean—Light which affects our eyes and light which does not. If you can arrange to have a look at light without allowing its æther waves to enter your eyes you certainly find that it is invisible; it looks exactly like darkness. It is true that if you are sitting in a totally dark room and you allow a beam of sunlight to enter through a slit in the window-shutter, you see the track of the beam, but this is simply due to little dust particles in the air reflecting the waves towards you. If the air were absolutely free of dust particles you would not see the track of the light across the room. We can perform this experiment upon a very grand scale. With the Sun as the source of light, and the shadow of our Earth as the dark room, we can look out on any cloudless night into the vastness of space. This space is continuously filled with æther waves of light sent out in all directions by the Sun, but we do not see these waves. Some of them fall upon a far-distant planet and then they are reflected towards our Earth, and when the æther waves enter our eyes we say we see the light of the planet. I think the meaning of visible and invisible light will be quite clear; all æther waves are in themselves invisible because the æther is invisible. We shall see later that only a very small range of æther waves affect our eyes.

We shall remember that when we speak of light travelling from the Sun to our Earth in about eight minutes we do not mean that there is any actual transfer of something from the one place to the other, but merely a wave-disturbance in the intervening medium.

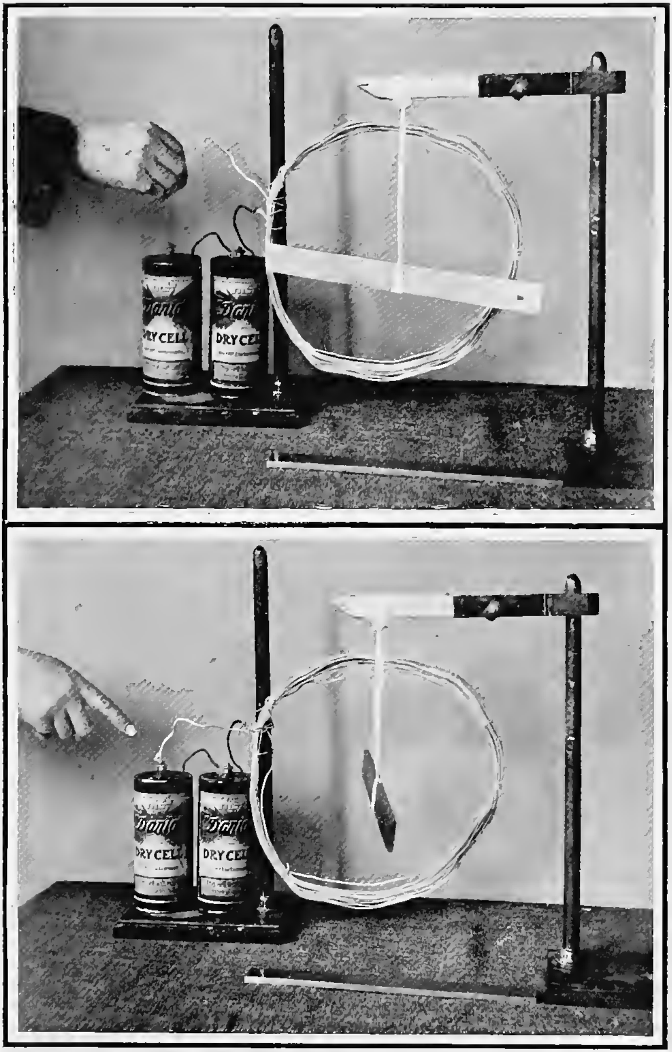
Perhaps the matter will be clearer if we consider the æther waves of radiant heat which the Sun sends out and some of which our Earth entraps. We are so accustomed to think of heat travelling along a body, and from one body to another by means of some material medium, that it is difficult at first to expel this idea from our minds when thinking of the Sun and the Earth. The space between the Sun and the Earth is not heated; there is merely an æther disturbance. We picture the particles of which the Sun is composed as being in a state of violent agitation or vibration. These vibrating particles of matter disturb the æther; the action, as we shall see later, is through some intermediate step, but that does not concern us at present. We simply picture the vibrating molecules of the Sun setting up a series of waves in the æther. These waves travel outwards through the great æther ocean, and some of the waves will, of course, fall upon our little planet, which is really no more than a speck in the universe. When these waves fall upon any matter they immediately set its molecules into vibratory motion, producing the condition we know as heat. You will notice that there has been a real transformation. Vibrating particles of matter cause an æther

disturbance which, at some great distance, is again transformed into the vibratory motion of other particles of matter.

When we speak to a distant friend by telephone, it is obvious that no sound passes from the one town to the other. The sound produced by the speaker controls an electric current which passes out to the distant station, and there it sets a metal diaphragm in motion, which causes the surrounding air to vibrate and reproduce the distant controlling sound. Just as no sound passes between the two distant places, no heat passes between the Sun and the Earth. In both cases there is a real transformation and reproduction.

It is only at the outset that the novice shakes his head at any mention of the æther. His first inclination is to say that we might as well talk about "the man in the moon." He may say that scientists have merely invented the idea of the æther to help them out of difficulties. The scientist admits the accusation. The idea of the æther was suggested by a great Dutch philosopher, Huygens,[1] more than two hundred years ago, to explain the phenomena of light. Sir Isaac Newton's more materialistic theory was much more popular, and even when the original philosopher, Dr. Thomas Young (London), adopted and worked out this æther idea, he met with little encouragement from scientific men. It is amusing to turn to an old number

[1] Long before this time æthers had been invented for the planets to swim in, and indeed to help the ancient philosophers out of any apparent difficulty, but the æther as we now accept it was definitely suggested by Huygens at the close of the seventeenth century.



A COIL OF WIRE CARRYING AN ELECTRIC CURRENT BEHAVES LIKE A MAGNET

In the upper illustration the battery is not connected to the coil. When the circuit is completed the large steel magnet swings round and takes up a position at right angles to the face of the coil, as in the lower photograph.

of *The Edinburgh Review* (vol. v. p. 97, 1804), and see how Young's ideas were attacked and ridiculed (see Appendix II., page 328). It is very remarkable indeed that so little credence was put upon the idea of the æther that when Young published a pamphlet, in answer to this attack in *The Edinburgh Review*, only one single copy was bought by the public.

We cannot, therefore, blame the man of to-day, who has not followed the trend of modern science, in finding it difficult to accept a bald statement as to the existence of the æther. He may say it is merely a theory, which he can believe or not as he thinks best. We quite agree with him, but at the same time we would ask him if he believes that the Earth goes round the Sun. This also is a theory. It is true that astronomers can prove by observed facts that the Earth *must* go round the Sun. In the same way the scientist can prove from observed facts that the æther *must* exist.

When any person of ordinary intelligence watches an old-fashioned performance of marionettes, his mind at once suggests that the puppets' arms and legs are being pulled upwards by strings, or threads, or *something*, although he cannot see any such connections. Common-sense tells him that some medium of communication *must* exist. When we look at a magnet drawing a sewing-needle towards it, or a large key, as shown at page 200, the same common-sense tells us that there *must* be some connecting medium. Indeed, if any one really considers the matter seriously, he is

forced to accept the theory of an all-pervading æther. A child soon learns in the nursery that if he wishes his little wooden horse to follow him about in his play he must have a piece of string, or some other medium of connection, between himself and the toy. Just as truly does the inquiring mind learn, in the nursery of science, that any two pieces of matter must have some intervening medium between them before the one body can act on the other. There is certainly no such thing as empty space. We may empty a glass globe of air and dust and all matter, by means of a mercury air-pump, but the glass globe is not empty; it is still filled with æther. If we have an electric bell inside the glass globe, we may set it ringing as energetically as we like, but it can no longer affect our ears; the medium of communication (the air) has been withdrawn. But in the vessel, beside the bell, we have a small electric glow-lamp, and we are making the experiments in the dark. We could not tell whether the bell was ringing or not, but as soon as the current is turned on to the electric lamp we are conscious that it is glowing. The lamp affects our eyes, although the bell did not affect our ears. It is clear that we have not succeeded in withdrawing the medium through which the lamp acts; the glass globe, though empty as far as ordinary matter is concerned, is still filled with the æther, and this æther is as real as the air we breathe.

That the æther pervades all space is quite apparent, for not only does it transmit light from the Sun, but

across many billions of miles from the distant stars. Our Earth, then, must be flying through the æther.

Picture a meteor approaching our Earth from interstellar space. As soon as the meteor enters the upper limits of our atmosphere the material of which the meteor is composed becomes white-hot. This is due to the enormous friction between the meteor and the particles of air, and is remarkable because the particles of air at such heights are comparatively few and far between. But the meteor is travelling at a great speed, probably not less than one thousand miles per minute. Our Earth is travelling at practically the same speed, through the æther, in its ceaseless journey around the Sun. We cannot find that any resistance whatever is offered by the æther through which we are literally flying. If there is any resistance, it must be so small that it has not appreciably affected our planet during man's tenancy of it.

The great Russian chemist, Mendeléeff, who established the *periodic law,* which we considered in an earlier chapter, firmly believed that the æther is an extremely thin gas. He supposed its particles to be so very small that they could pass, with perfect ease, between the atoms of matter, so that all matter was perfectly porous to the æther. The physicists of to-day are not inclined to accept this theory; it is too materialistic, and yet it is not altogether inconceivable.

The youth at school is somewhat surprised when he learns, for the first time, that gases may pass through the solid walls of unglazed porcelain vessels, while the

same vessels will hold water without any of it escaping. The student is more surprised when he learns, from Lenard's experiments with cathode rays, that electrons may pass with ease through a solid aluminium shutter, through which it is impossible for any gas to pass. We have only to go a step further and imagine particles of æther which may pass through all substances with perfect ease. These æther particles may be as much smaller than electrons, as electrons are smaller than atoms, and, indeed, if that be their size, Mendeléeff could find a place for them in his revised table of the periodic law. It must be clearly understood that this theory of Mendeléeff's is no more than a suggestion, and that the idea does not find much favour with the scientists of to-day. We have other mechanical theories as to the actions of the æther, but we have no other theory regarding the nature of the æther.

We have been brought up to look upon the æther as a mysterious "something" quite apart from ordinary matter; it is therefore difficult to credit the æther with any granular construction, as suggested by the great Russian chemist. At present we can only guess. In any case we have the very interesting electron theory which sets forth the following creed:—

The atom is composed of very small particles called electrons, and the atom is practically a miniature solar system. It may be that a future generation will accept a creed which shall teach that the electron in its turn is composed of small particles of æther, also

moving in regular orbits, within the electron, and if so, what next? This, however, is going beyond our province, for these suggestions would not be acknowledged as scientific ideas of to-day.

While the idea of the granular construction of the æther is not generally accepted, there is practically a unanimous agreement that the æther, whatever its nature, is the primal substance of which all matter is formed.

It is not so very long ago that the late Lord Salisbury remarked that the æther seemed to him to be the nominative case of the verb *to undulate*, for we know practically nothing of the nature of the æther but that it can vibrate or undulate. We need not dwell any further upon speculations as to the nature of the æther; we have plenty to interest us in considering the actions which take place in this all-pervading medium.

The æther is indeed marvellous in its capabilities for transmitting all sorts of waves. The Sun sets up certain waves in the æther, and we call these *light* waves. If we analyse these waves by passing them through a glass prism we find a great variety of wave-lengths. Only a very small portion of this variety affects our eyes, and causes the different colour sensations. By placing a sensitive thermometer in the dark space beyond the visible red end of the spectrum we find that there are "invisible" waves present which produce heat. At the other end of the spectrum, beyond the patch of violet colour, we also "see

darkness." Here we find waves which will affect a photographic plate, and exhibit other chemical actions. Even if the æther could do no more than what has been mentioned in this paragraph, it would be truly marvellous, for it is transmitting all this great variety of waves at one and the same time.

When one looks at an ordinary street light at night, it is difficult at first to realise that the electric arc, or the white-hot gas mantle, is setting up all this variety of waves in the æther.

Even these do not exhaust the capabilities of the æther, for when we set an X-ray tube to work, we cause quite a different kind of disturbance in this same medium. These Röntgen rays are different from light waves; the former can penetrate such substances as wood and human flesh, both of which are opaque to light. We shall return to a further consideration of X-rays later; at present we merely wish to notice that they consist of a disturbance in the æther.

It is the same protean æther which carries the electric waves set up by a wireless telegraph transmitter, which waves falling upon the distant receiver set it in motion. It must also be by means of the æther that one lump of matter attracts every other lump of matter, but as to the nature of gravitation we have really no idea even in this enlightened age.

There is one point which I find puzzles some people—how it is that these æther waves can travel millions of miles and yet keep up a constant speed throughout their journey? All the waves in the æther

travel at the rate of somewhere over eleven million miles per minute. I find that the ordinary man is more impressed with these figures than with the orthodox 186,000 miles per second. When we come to consider *Light*, we shall see how its speed of travel has been determined; in the meantime we merely wish to see how the speed is constant, and does not fall off as the distance increases.

As the speed of light is so great, the time it takes to reach us—say, from some far-distant lighthouse—is quite inappreciable. When, however, we consider the passage of light waves from the Sun to the Earth, we find that they take about eight minutes to cover the ninety-two million miles separating us from the Sun. We require to bestir our imaginations to think of light waves taking thousands of years to reach us from some of the distant stars, and yet this is really what does happen.

The difficulty which some people have in picturing a constant speed of travel over billions of miles is really due to a misunderstanding. Possibly they think of bullets and other pieces of matter being projected with great velocity, but quickly losing speed until they ultimately come to a state of rest. Try to picture a sound wave travelling through the air. It is true that the energy of the sound wave spreads out and dies away at a distance, but during its whole journey it has maintained the same speed. Wherein lies the difference? In the first case a piece of matter was moved from one part of the Earth to another, and

as it went it had to combat two resistances—collision with the molecules of air, and the attractive force of gravitation. In the second case there was no transference of matter from the one place to the other; there was simply a series of waves set up in the air. When you set up waves in the centre of a pool of water, you do not send water from the centre to the shore of the pool. The Sun and stars merely cause waves in the æther, hence the rate of travel is constant. The energy of sound waves, or water waves, dies away with the increase of distance travelled, and so must the energy of the æther waves. A blazing sun placed at a great distance only appears as a faint star. It may be that its æther waves have been so diminished in their long journey that they fail to stimulate the nervous mechanism of our eyes, and we only know of the existence of the far-distant star because these greatly diminished æther waves are still able to affect the chemicals upon a photographic plate.

Sound waves are only constant in speed as long as the medium through which they are being transmitted is constant. A difference of temperature in the air alters the rate of travel of waves in it. In the same way the velocity of æther waves is constant as long as they remain in the ocean of pure æther, such as we have throughout interstellar space. When, however, these waves leave the boundary of the pure æther ocean and enter our atmosphere they do meet with some resistance, and when they enter water their rate of

travel is appreciably lessened, while their progress is completely barred by substances which are *opaque*.

In the earlier chapters we have tried to picture the atomic structure of matter, and the electrons revolving within the atoms, and now we seek to add to this picture the great illimitable ocean of æther, surrounding and pervading all matter. It is in this surrounding æther that magnetic and electric *fields* exist. We have therefore to deal not only with electricity in matter, but also in this surrounding medium. In this connection it will be of interest to see, first of all, what magnetism is.

CHAPTER VII

WHAT IS MAGNETISM?

What produces a magnetic field?—A real æther disturbance—How a piece of iron becomes a magnet—Molecular magnets—A permanent magnet—Interesting facts concerning the magnetisation of iron ships—Causes of magnetisation—A kitchen poker in the disturbed æther—How the iron molecule is magnetic—The most efficient kind of magnet—Where the energy comes from—Demonstration of the reality of the æther disturbance—Some illustrations of Faraday's lines of force

THE popular idea of a magnet is simply that of a piece of iron or steel which possesses a strange property of attracting other pieces of common iron or steel towards it. Most of us, however, have become familiar with the fact that a coil of wire through which an electric current is flowing also behaves exactly like an ordinary magnet (see illustration facing page 94).

In an earlier chapter we have noted the magnetic field produced in the æther around a magnet. Let us inquire what it is that produces this magnetic field. Taking, in the first place, the case of a magnetic field surrounding a wire which is carrying an electric current, we picture a flow of electrons within the wire. Electrons are being handed along from atom to atom. Is it possible that this simple locomotion

of electrons can so disturb the surrounding æther as to produce a magnetic field? The idea that electrically charged bodies, moving with a steady motion at a great velocity, would produce a magnetic field is not a new one. This was an accepted fact before the discovery of electrons. Therefore, when the electron theory sets forth that a magnetic field is due to the steady motion of electricity in a conductor we have no difficulty in accepting this part of the creed. The more electrons that are passing in a given time, the greater is the disturbance in the surrounding æther.

Seeing that all magnetic fields are due to a steady locomotion of electrons, we have no hesitation in saying that there must be a steady flow of electrons within a piece of magnetised iron. If this were not the case we could not have the magnetic field surrounding it. But we need not suppose that the electrons travel round and round the lump of iron or steel, for we shall see that the electrons revolving around their atoms may, under certain conditions, produce the same result. To help our imagination we may picture the atoms with their revolving electrons to be something like miniature Saturns with their revolving rings. In the iron we see a myriad of little Saturns grouped together, but with their rings lying in all directions, a perfect higgledy-piggledy[1] congregation. In such a condition

[1] While we picture the atoms to be in a higgledy-piggledy condition, it should be understood that there is some method in their madness. They really set themselves into little stable rings, or groups; the result, however, may be conveniently described as higgledy-piggledy or topsy-turvy.

the steady motion of an electron around one atom would set up an æther disturbance exactly opposed to that set up by a neighbouring atom whose ring happened to be in an opposite position to that of the first atom. All the atoms would be "at sixes and sevens," and the work done by one would be neutralised by another. In this condition, a lump of matter would show no magnetic field. If by any means we could set all the atoms into such positions that their electron orbits, or rings, were all in the same plane, then we should get a result as illustrated in Fig. A.

Here we see six atoms with their electron orbits placed in the same plane. We may imagine this to be the section of a piece of magnetised iron.

It will be observed that there is the *equivalent* of a flow of electrons around the magnet. The æther will be disturbed in the same manner as it would be if the electrons really went round and round the lump of iron instead of each going round its own little orbit. The condition of things is, therefore, just as though we had a wire, forming a waist-belt around the lump of iron, with an electron current flowing in the wire. We should then have a magnetic field around this imaginary wire.

Leaving the electron part, of the foregoing, out of account, this theory of magnetism has been accepted for two or three generations. We have been in the habit of picturing each molecule of iron as a little magnet, having a north and a south pole. In the ordinary condition of iron we have supposed the little

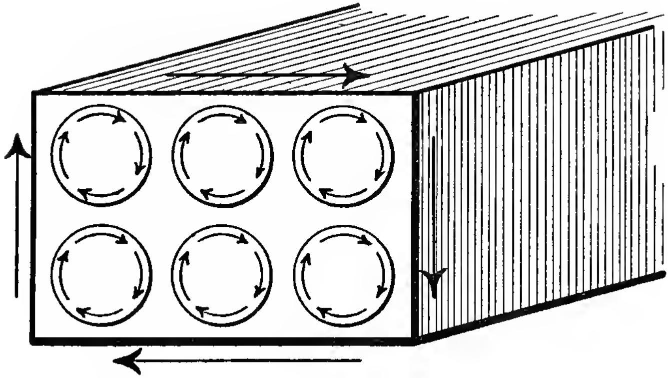


FIG. *A*

Internal arrangement of a Steel Magnet

This diagram shows one end of a bar magnet, and the six small circles represent some of the atoms of which the steel bar is composed. The small arrows indicate the directions in which the satellite electrons are revolving around the atoms. It will be observed that the combined motion of the electrons is equivalent to an electron current going round the body of the magnet, as indicated by the large arrows. In the text we see that a steady locomotion of electrons disturbs the surrounding æther, producing what we know as a magnetic field around the steel bar.

magnets to be lying topsy-turvy, so that one neutralises the action of the other, and there is no outward magnetic effect. But when the iron is stroked by a magnet, these little molecular magnets are forced to turn round and place all their north poles in one direction. The myriad of little molecular magnets acting together can produce quite an appreciable magnetic field in the surrounding æther. At the one end of the iron we find all the molecular north poles facing outwards, while at the other end we find all the south poles facing outwards. Hence the magnetised piece of iron exhibits distinct north and south poles. If we cut the magnet in two, we shall still have a north pole at one end of each piece and a south pole at the other.

Many facts have been brought forward to support this molecular theory of magnetism. We find that when the molecules of hard steel have been turned round, under the influence of a magnet, they do not turn back readily to their old positions. Hence we find that the steel remains a "permanent" magnet. We could disturb this molecular arrangement by hammering the steel, or by heating it to a red-heat. In the former case we should find very soon that the magnet was considerably weaker after a good hammering, while in the second case we should find that we had completely "destroyed" the magnetism by heat, the molecules having been enabled to return to their former topsy-turvy condition.

When an iron ship is being built the magnetic poles

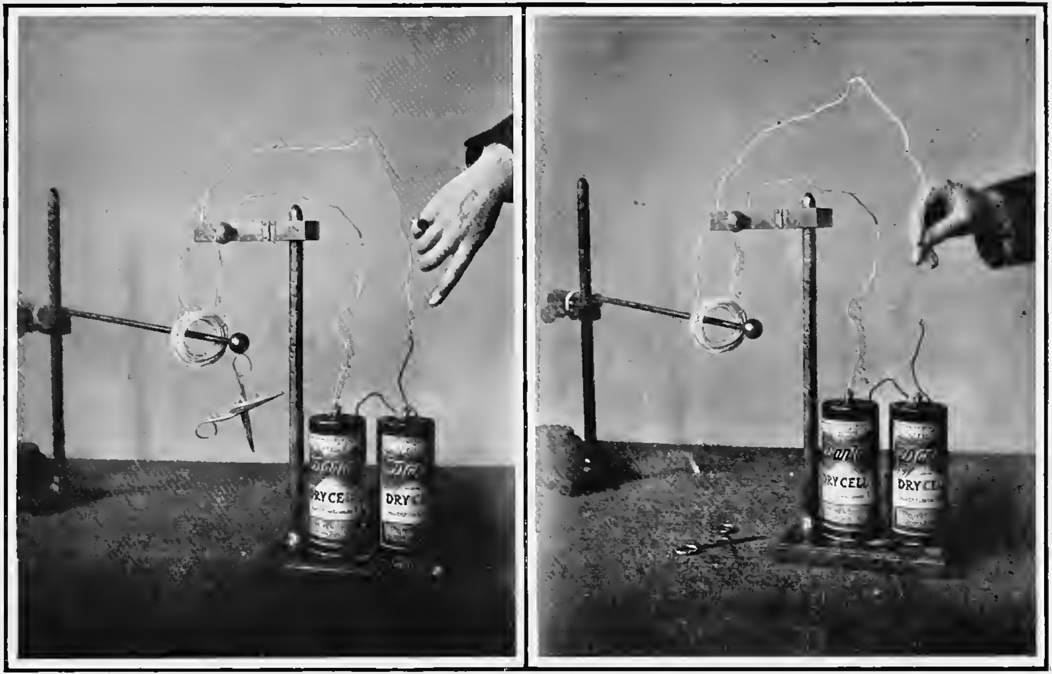
of the Earth seek to turn the molecular magnets of the metal so that they may lie with their magnetic poles north and south. It is very remarkable how quickly the hammering in of the rivets enables the molecular magnets to obey the Earth's pull. Some interesting experiments were made recently on the hull of a cargo-steamer during the period of building. Owing to a strike of the riveters the whole ship was completely plated and all bulkheads and decks built in, while only about five per cent. of the rivets were fixed. A careful note was taken of the ship's magnetism. We are considering the ship as a piece of iron which the Earth is seeking to magnetise. We shall suppose that the amount of magnetism due to the ship was, at this stage, only twenty-five per cent. of that due to the Earth itself. Things remained as they were for a month, till the riveters set to work once more. Then the molecular magnets got a better chance of obeying the Earth's pull. By the time the riveters had forty per cent. of the rivets hammered in, the ship's magnetism had increased by more than thirty per cent., and it went on increasing as the hammering continued.

We have considered two causes of magnetism. We might call the first *natural* magnetisation, in which iron is magnetised by the influence of the Earth's magnetism. This is the cause of natural magnets or *lodestones* found in the Earth. The second cause, already dealt with, is the magnetisation due to stroking the iron with a permanent magnet. We are aware of other means of influencing these little molecular

magnets. We know that if we place a magnet in the neighbourhood of a coil of wire in which an electron current is flowing (as shown in the illustration facing page 94), the magnet at once turns round and places itself at right angles to the face of the coil. Look at this illustration and try to imagine the magnet needle to be a greatly enlarged molecule in a piece of iron which the coil of wire is supposed to encircle. We see the magnified molecule turn round when the current passes through the encircling wire. It is not a difficult task to picture the whole space within the coil to be filled with similar magnets, all of which will obey the influence of the magnetic field. In this way we may form a clear idea of what takes place within a piece of iron when surrounded by a wire carrying an electron current.

In the illustration facing this page we see what happens when we place an ordinary kitchen poker in the disturbed æther within the coil. The myriad of molecular magnets within the iron poker are turned round so that they act together, and this army of little molecules is able to support a pair of scissors.

Every atom of matter—whatever name it may go under—is made up of electrons moving in steady orbits. We therefore find magnetic effects in every substance, although these are in most cases very small. The magnetic effects in nickel and cobalt are quite appreciable though much less energetic than in iron. Many alloys of copper, manganese, and aluminium show very fair magnetic effects, but



AN ÆTHER DISTURBANCE AROUND AN ELECTRON CURRENT

In the left-hand photograph an electric current is passing through the coil. When a poker is placed in the disturbed æther within the coil, the poker becomes a magnet and is able to support a pair of scissors. As soon as the electric current is withdrawn, as in the second photograph, the æther disturbance ceases and the poker loses its magnetism, so that it cannot support the scissors.

iron stands head and shoulders above them all. There must be some special feature in the construction of the atom of iron which acts upon the æther much more vigorously than other atoms do. It has been suggested that one or more of the electrons in the iron atom describe a much larger orbit than is usual in atoms; that they are somewhat analogous to comets circling around the Earth. The motion of these electrons is not under man's control; they are incessantly moving in the iron. Any piece of iron contains the magnetic power, but, as we have already seen, it is not apparent unless the multitude of little magnetic fields are all acting together in one plane; unless all the little Saturns have their rings lying in one direction. In this condition the iron is magnetised.

If the magnetic force of iron is really a self-contained force, one would expect that there should be a definite limit to its power. Long ago this was found to be the case; it became apparent that magnetism was not something which we were putting into the iron, as when we charge a body with electricity. In the case of a magnet we found that we soon reached a point beyond which it was quite impossible to increase the magnetism, and this was christened the "saturation point." Just as in many other christenings, the name was not very wisely chosen. The word *saturation* at once conjures up ideas of soaking something into the iron. However, in the light of present-day knowledge, we understand that we have

reached the limit when we have succeeded in turning the little Saturns round into as good positions as it is possible. We have as perfect a combination of their little forces as we can obtain.

It is quite clear what kind of magnet will give us the best result. We get a magnetic field from a coil of wire in which an electron current is flowing, but this is a comparatively weak field. This magnetic field, however, can act upon the myriad of little magnetic forces locked up in a piece of iron. Therefore our best plan is to place a coil of wire around a piece of iron, and keep an electron current flowing in the wire by means of a battery, or other "electric pump."

It will be apparent that the foregoing arrangement will give us the best kind of magnet which is possible. As the particles of soft iron are more easily affected by the current than those of hard steel are, we make the cores of *electro-magnets* of soft iron. There is a further advantage in this, for as soon as the controlling electron current in the wire is stopped, the myriad of little magnetic forces in the iron return to their higgledy-piggledy positions, and all trace of magnetism has gone. We therefore have a magnet which will attract and let go at will. I have already explained the manifold applications of such magnets in the first book of this series, "Electricity of To-day."

We must not run away with the idea that the soft iron core of an electro-magnet merely concentrates the magnetic field surrounding the coil. The weak magnetic field of the coil calls into play the internal

forces of the soft iron. We may increase the magnetic field around a coil of wire by increasing the flow of electrons through the wire, but the magnetic energy contained in a piece of iron is constant. The magnet is only more or less powerful because its atomic electron currents are brought into more or less concerted action.

In iron and other magnetic bodies we suppose that the orbits of the active electrons are large enough to act upon each other across the space between the atoms. In this respect iron is pre-eminent, while Dr. Heusler's alloys, to which I have already referred, make humble seconds, and cobalt and nickel make distant thirds.

In the illustration at page 200 I have endeavoured to show that the magnetic field is a real æther disturbance. You see a common iron poker placed at some distance from a large electro-magnet, and yet the particles of the soft iron poker are affected by the disturbed æther to such an extent that the poker is able to attract a key against the force of gravity. The intervening air has nothing to do with conveying the power, for the experiment might be performed in a vacuum. There is a real æther disturbance around the large electro-magnet, and this æther disturbance has a real effect upon the iron, causing the myriad of little molecular magnets contained in the iron to fall in line with one another and combine their forces.

In the second photograph we see a key being drawn up towards the magnet by the æther disturbance. No

one will suppose that the finger has been magnetised; it is merely preventing the key from reaching the magnet. If we were to fasten a string to the key and tether it to the ground, we should see the key supported in mid-air, for the string would serve the same purpose as the finger does in the illustration.

Long before the birth of the electron theory, Faraday pictured *lines of force* existing in the æther around a magnet. In order to demonstrate the existence of such lines, one may sprinkle iron filings upon a sheet of paper, and when the pole of a magnet is placed beneath the paper, the filings set themselves along those lines of force. In the photograph facing page 122 I have reproduced some of the figures obtained in this way by students in the Glasgow and West of Scotland Technical College. In order that the filings may be retained in the positions which they take up, the paper is coated with paraffin wax. After the figures are formed, the paper is heated so that the filings become attached to the paraffin wax when it cools. Here again we have a demonstration of one set of molecules being brought within molecular range of another set so that they can attract one another with the force of cohesion.

In the present chapter we have been considering the disturbance in the æther due to the steady motion of electrons. The locomotion of electrons along a wire produce a magnetic field around the wire. It will be of interest to see what effect the starting and stopping of these electrons may produce in the surrounding æther.

CHAPTER VIII

MORE ABOUT ELECTRONS IN MOTION

Matter is very lazy about moving—Perpetual motion on a grand scale—Moving matter is unwilling to stop—The moving electrons—Electrons affect other distant electrons through the medium of the æther—An interesting telephonic trouble The æther conveys the energy—The function of the telegraph wire—An analogy of electric induction—Some "wireless" experiments—Self-induction—Electrons affected by a moving magnetic field—Faraday's great discovery—How the electric current is produced by the dynamo

In our practical workaday life we soon realise the fact that all matter is very lazy; it requires a good push to start it into motion. We see a man pulling very hard in his endeavours to get a heavily laden barrow to move, when some kindly disposed passer-by gives the unwilling barrow an additional push and off it goes, the man in charge being able to keep it going.

It is equally true that all matter is just as lazy or unwilling to stop when it is once set in motion. Of course the barrow-man would find it very difficult to believe this, as he has to strain every muscle to keep the barrow moving. That, however, is due to the great friction between the wheels of the barrow and the surface of the road. Let him get his barrow on to the tramway rails, and he will find that about

one-half of his load has apparently disappeared. It is obvious that the friction has been very greatly reduced; there is not the same resistance to the movement of the wheels. Let him take the wheels off his barrow and then try to pull it along; he would find it quite impossible to move it. The barrow-man would, doubtless, be willing to admit that at least a very great deal must depend upon the frictional resistance, although he might not be able to endorse the statement that matter is just as lazy to stop moving as it is to start into motion.

The planets meet with no friction or resistance in their long journeys around the Sun, and in their continual movement we see true perpetual motion. But I fear that even this grand demonstration by Nature would not convince the hard-worked barrow-man that but for the resistance offered by outside sources his barrow would continue to move of its own accord.

If we think of a bullet fired from a powerful gun, we can realise that once on its way it is certainly unwilling to stop, and indeed unless any obstructing obstacle offers considerable resistance the bullet will force its way through the obstacle. Ultimately the bullet is brought to a state of rest by the resistance of the air and by gravitation pulling the bullet down to the Earth. The truth is that it is only because we are so accustomed to see all moving bodies brought to rest, that we have difficulty in realising that this condition is only brought about by the interference of

outside forces. If we consider the subject seriously we shall soon realise that matter of itself is just as lazy to stop moving as it is to start into motion. This property of matter has been called its *inertia*, from the Latin word *inertis*, signifying *inactive*.

All that has just been said of ordinary matter is also true of the invisible electrons. They possess this property of inertia ; they are just as inert as matter. The electrons, like the heavy barrow, require an additional expenditure of energy to set them into motion, and when moving they will not stop until some outside force is applied. When the flying electrons escaped from the vacuum tube by means of an aluminium window they were moving with a velocity of many thousands of miles per second, and yet they were pulled up within an inch by the resistance of the particles of gases forming the air. The electrons would not have stopped of their own accord. Just as we see perpetual motion in the heavens, so do we see, with our mind's eye, perpetual motion of the electrons within the atom, where they meet with no resistance. They are in motion, they have no inclination to stop, and there is nothing to stop them.

Let us consider what happens when we start and stop an electron current in a wire. We find that if there is another wire in the neighbourhood, and lying parallel to the first wire, there is a disturbance of the electrons in this wire. Each time that the current is started and stopped in the first wire there is a

momentary current set up in the second wire. The Telephone Companies found this a source of much trouble at first. Two telephone wires running parallel to one another on the same poles enabled a third party to hear the conversation passing on the neighbouring wire between other two subscribers. The telephone engineers found it necessary to wire the lines in a special manner, causing them to cross each other from one side of the poles to the other, so that the lines were no longer parallel. I am referring to the time when the telephones were worked over single lines and an earth circuit. Now that complete metallic circuits are used the trouble is not apparent unless on very long lines. I remember hearing of the following notable incident, which occurred some twenty years ago :—

Some of the telephone subscribers in London complained of clicking sounds in their telephones, and these noises became annoying during a conversation. It was found that these subscribers' lines passed along a certain street under which some telegraph cables were laid, and there could be no mistaking the cause of the annoying clicks ; they were, undoubtedly, the well-known Morse telegraph signals. The telephone wires were on poles on the top of high buildings, while the telegraph wires were buried in the earth, and yet the electron current in the subterraneous wires was undoubtedly causing electrons to move in the telephone wires overhead. How could the electrons in the one wire affect those in the other wire ? Only by disturb-

ing the intervening æther, which in turn disturbs the electrons in the second wire.

It may be well to mention, at this point, that even in the single case of an electric current flowing along a wire, say, to a distant telegraph instrument, or to an electric-bell, the energy is really transmitted through the æther surrounding the wire. It is in the æther that the electric and magnetic fields or lines of force exist, and it is these two forces acting conjointly that cause energy to be transmitted by the æther surrounding the wire. It is customary to say that the telegraph wire merely acts as a guide to the æther disturbance, but the wire is more than a mere guide. It is within the wire that the electrons move, and thus disturb the surrounding æther by the motion of their electric and magnetic fields.

Returning to the consideration of two wires lying parallel to one another, we find that when we start the electrons in the first wire there is a momentary electron current set up or *induced* in the second wire. This disturbance, however, only takes place in the second wire, at the moment the electrons are started and stopped in the first wire. It is interesting to note the direction of these momentary currents, and to simplify matters we shall consider an analogy.

If a passenger is standing in a train or tramway car which is at rest, when it suddenly starts forward the passenger receives a sharp lurch backwards, or in the opposite direction to the force producing the forward motion of the vehicle. In a somewhat similar manner

the electrons in the second wire receive a sudden lurch back in the opposite direction to the controlling current in the first wire. Then, again, if a train or car, travelling at a fair speed, is suddenly stopped, the passenger standing in it is thrown forward in the direction in which the vehicle had been moving. Just so do the electrons in the second wire receive a forward motion when the current in the first wire is stopped. A passenger is more likely to meet with serious hurt through the sudden stoppage rather than the sudden starting of a train. In the former case the change of motion is much greater. A train may be moving at forty miles per hour when its motion is almost instantaneously brought to zero. But in starting from zero the change is much more gradual; it is impossible to suddenly change the motion of a train from zero to forty miles per hour. The same holds good in the case of the electron. When the electrons are suddenly stopped in the first wire the effect in the surrounding æther is far greater than was the case when they were started into motion. Hence of the two momentary currents produced in the second wire, that due to the stopping of the controlling current in the first wire is by far the most important. So much is this the case that we can often afford to neglect the momentary current due to the starting.

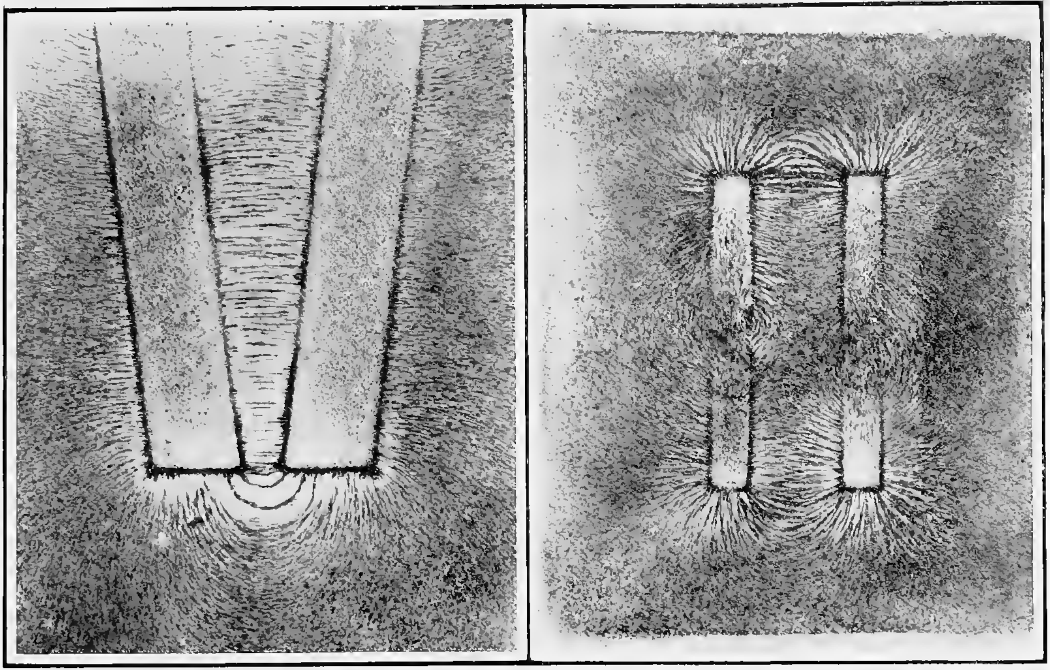
As long as the electron current is flowing steadily in the first wire there is a steady transmission of energy in the æther surrounding it, but the electrons in the second wire are not affected in any way. It is only at

the moment of starting and stopping the electrons that the electrons in the second wire are set momentarily into motion.

It is natural to inquire the distance one wire may be from another and yet cause the electrons in the second wire to move. Sir William Preece, when acting as engineer-in-chief to the British Post Office, succeeded in setting up or inducing a current in this manner when the two lengths of parallel wires were several miles apart. This was one of the earliest methods of wireless telegraphy, but it was precluded from working over any great distance; for as the distance between the two wires was increased, so had the length of the two parallel wires to be correspondingly increased. This difficulty could have been overcome if the long wires would have acted in the same way when rolled up into the form of two large coils. This, however, is impossible, for then the whole æther disturbance is concentrated, so that the disturbed æther reacts upon other electrons in the same coil, and we have what we describe as *self-induction.* Before the electrons in one coil can act upon the second coil, the two coils must be near one another. We have a practical application of the action between two neighbouring coils in the *induction coil* already mentioned, and with which most people have become familiar in connection with the production of X-rays.

What we wish to observe at present is that the momentary currents in the second coil are caused by setting up and withdrawing a magnetic field, or in

other words, by a moving magnetic field. In the case which we have been considering, we have an electron current quickly started and stopped in a coil of wire. Each time the electrons start into motion there will be a magnetic field formed around the wire, which will be withdrawn as the electrons stop moving. We may picture magnetic lines of force being suddenly thrown outwards from the wire and then withdrawn. But any moving magnetic field will serve the same purpose. We may move a simple steel magnet in the neighbourhood of a coil of wire, and we induce the same momentary currents in the coil. We may let the magnet remain at rest and move the coil of wire into and out of the magnetic field, and the result is just the same. This was Michael Faraday's great discovery. When experimenting at the Royal Institution, London, in the year 1831, he discovered that when he moved a coil of wire between the poles of a magnet there was an electric current induced in the coil. Faraday pictured the moving coil cutting through the magnetic lines of force, and as a result of this there was a momentary electric current induced in the coil of wire. To-day we form a more detailed picture. In imagination we see electrons moving around the atoms of steel in the so-called permanent magnet. These moving electrons disturb the surrounding æther, producing that state which we call a magnetic field. Then as the coil of wire is quickly plunged into this disturbed æther, we see a sudden activity among the electrons surrounding the copper atoms in the wire. Electrons are



LINES OF FORCE AROUND A MAGNET

The above photographs show how iron filings will arrange themselves along the lines of force surrounding a magnet.

hustled along from one atom to another, and these moving electrons constitute what we call an electric current.

It is obvious that it is quite immaterial whether we move the coil of wire in the neighbourhood of the magnet or move the magnet in the neighbourhood of the coil. It is generally more convenient to move the coil and let the magnet stay at rest.

It will be of interest to form a clear mental picture of the manner in which the electrons behave in the coil of wire as it enters and leaves the magnetic field. Keeping before us the analogy of the passenger in the jolting train, we picture the electrons in the moving wire receiving a sudden lurch in one direction as they enter the magnetic field, and then a sudden lurch in the opposite direction as the wire is freed from the magnetic field. We have seen the effect produced in one wire when the electrons are suddenly started and stopped in a neighbouring wire. In that case we found that the effect produced by the more sudden stopping of the electrons was much greater than that caused by the more gradual starting. But in the present case the conditions are quite different. The electrons producing the magnetic field are in constant and regular motion within the steel magnet, and it is the electrons in the copper wire which are suddenly brought into the magnetic field and then withdrawn. The suddenness with which the electrons enter the magnetic field is just the same as the suddenness with which they leave the field, so that in this case the electrons lurch in one

direction just as much as they lurch in the other. If the coil is kept rotating uniformly so that the wire enters and leaves the magnetic field at a constant speed, there will be a regular to-and-fro motion of the electrons in the wire. This rapid swinging to and fro of the electrons is what we call an *alternating current* of electricity.

A *dynamo* is a simple machine in which a coil of wire called the *armature* is quickly rotated between the poles of a powerful magnet. In the armature of all dynamos there is this to and fro or alternating current, a surging to and fro of the electrons. As explained when dealing with the practical side of the subject in the first book of this series—"Electricity of To-day"—we may lead out this to-and-fro current into the electric mains, or we may, by means of a commutator, cause this alternating current in the armature to set up a direct or continuous current in the outer mains.

The dynamo is the best means we have discovered of setting the electrons in motion on a large scale. If we only require a small electric current, it is more convenient to set the electrons in motion by chemical means, as in the ordinary battery, but for large currents we depend upon the mechanical motion of a dynamo.

In the battery we see chemical energy transformed into electrical energy, while in the dynamo we see mechanical energy transformed into electrical energy. It would be quite natural to inquire, at this point, what *energy* really is.

CHAPTER IX

WHAT IS ENERGY?

Energy in different forms—Definition of Energy—Transferring energy—Energy as indestructible as matter—Meaning of kinetic and potential energy—Heat energy—The vibration energy of a muscle—Motion—Why the temperature of water cannot exceed boiling-point—Transformation of energy—Chemical energy and electrical energy—The conservation of energy

THE protean actor used to amuse our grandfathers, and even now he appears occasionally at entertainments. Sometimes he would represent four or five different characters in the one act. He would be before the audience as a mischievous boy, when he would pretend to hear his grandfather coming. The boy would run behind some article of furniture, whereupon the door would open immediately and in would come an old gentleman. Indeed so quickly was the transformation made that one could hardly believe that the two characters were represented by the one actor. Energy is a grand protean actor; it appears in at least eight distinct forms, and its changes from one form to another are instantaneous.

The usual definition of Energy is capacity for doing work, and we say that work is done when force is overcome through space. It will be observed that

the words *energy* and *force* have distinctive meanings in science, although we often use the one word for the other in ordinary speech. Force is any cause which alters a body's state of rest or of uniform motion in a straight line.

So far we might say that force is the power or ability of setting bodies in motion, but this is not all. If a body is already in motion we require to expend some force to stop it. A man is wheeling a heavily loaded barrow down a steep hill when he finds that it is getting beyond his control. Some energetic onlooker rushes to his assistance, and with their united forces they succeed in stopping the would-be runaway barrow.

We recognise the foregoing statement as the first law of motion, which was clearly stated by Sir Isaac Newton more than two centuries ago. Although the three *laws of motion*, which were clearly set down by Newton, are known as *Newton's laws*, it is of interest to remember that these were really discovered by poor old Galileo after he had suffered much at the hands of the Inquisition. At the time he wrote his famous dialogues on motion he was practically a prisoner, having been ordered never to leave his house and to receive no visitors.

In the illustration facing page 134, we see the suggestion that a small force—the man's breath—might supply energy enough to uproot a tree, but it will be observed that the force is of no practical use for that purpose, as it would require to be applied continuously for six hundred thousand years

before the necessary energy could be supplied in this way.

When a football player is about to kick off, the ball is placed at rest upon the ground, the player makes a quick forward movement of his foot and imparts considerable energy to the ball. A very good demonstration of one body transferring energy to another is seen during a game of billiards. A quickly moving ball strikes a stationary ball "full," whereupon the whole energy is apparently transferred to the second ball, while the first is suddenly brought to rest.

We have no difficulty in realising the fact that energy may be transferred from one body to another, but this transference does not take place indefinitely without an apparent loss. Picture a long row of billiard balls arranged in one straight line, and each standing a little distance apart from its neighbour. We imagine the first ball to strike the second one full and to deliver up its energy to the second, which in turn passes it on to the third, and so on along the line. But as the energy is handed on to the more distant balls we see a serious diminution in the amount of energy exerted, and if the row is long enough the whole energy is finally dissipated. We cannot say it is destroyed, for we can no more destroy or create energy than we can destroy or create the other entities, matter and æther. We have become familiar with the fact that at the creation of the world a certain definite amount of matter was placed in this planet, and we should become equally familiar with the idea that a

definite amount of energy was also placed in the world. We cannot add to nor subtract from the total sum of matter; we can only transform it from one kind to another. It is exactly the same with energy; we can neither add to nor subtract from the total sum; we can only transform it from one kind to another.

When the energy which was transferred to the first billiard ball was passed on and on till it ultimately disappeared, where did it go? It must still exist, as it is indestructible; it has gone into the forms of sound and heat. We shall understand this matter better if we consider, first of all, the different forms which energy may take.

The form of energy which is most conspicuous is the energy of moving matter. We must have definite names for energy as it appears in its different forms. We might call this first form the *energy of motion.* The meaning will become clear if we take a single example. A billiard ball when moving possesses energy of motion; it possesses the ability to cause other billiard balls to move. This form of energy has a more distinctive name given to it—*kinetic energy.* This name is derived from the Greek verb *kineo,* I move. The introductory branch of the science of mechanics which deals with motions is called *kinematics,* and we recognise the same idea of motion in the word *kinematograph,* although it is more commonly spelt *cinematograph.* Here, then, we have one distinct *form* of energy—the energy of motion, or kinetic energy.

When we wish to impart energy of motion to an

arrow, we strain the bow and then suddenly release it, when off flies the arrow possessed of considerable kinetic energy. It was the bow which set the arrow in motion, therefore the strained bow possessed potential energy. We might call this the *energy of strain*, but as the actual straining is not so apparent in all cases, this form of energy has been given a distinctive name. It has been called *potential energy*, from the Latin *potentia*, meaning power. This title does not appear to one at first as being very expressive. Indeed, one might be inclined to think that a flying arrow also possessed potential energy because it possesses power, but that would be a wrong use of the word. Potential energy is the name given to that form of energy, not only represented by an actual strain or deformation, but of any body placed in such a position that when freed it can do work. When we raise the weights of an old grandfather's clock we have given the weights potential energy, although we cannot so easily think of a strain in this case, as, for instance, when we wind up the mainspring of a watch. In the latter case the strain put upon the mainspring is most apparent, and we say that it possesses potential energy. It is obvious that potential energy may be transformed into kinetic energy, or in other words, that the energy of strain may be converted into the energy of motion. Witness the strained bow and the arrow, the raised weights falling when released, and so on.

I think it will simplify matters if we understand that all forms of energy must come under one or other of

these two classes. Energy must either be kinetic or potential; the ability to do work can only be possessed by a body already in motion, or by a body held under a strain. We may speak of gravitational energy, but that is merely a subdivision; it is supposed to be a case of strain in the æther. We pull a stone away from the earth, and the earth pulls the stone back again.

Consider the motion of any pendulum. While it is hanging at rest it has no energy, but when we pull it to one side we raise the weighted end of it against the pull of gravity; we expend some energy in doing so. In this case we have given the pendulum energy of strain, or potential energy, which, as soon as the pendulum is freed, is transformed into energy of motion, or kinetic energy. It will be observed that as it falls it gradually loses its potential energy and gains kinetic energy. It is carried past its position of rest, and rises on the other side from which it started. As it rises it gradually loses its energy of motion and gains energy of strain, till at the topmost point of its swing it has lost all its kinetic energy and has only potential energy. Then it passes through the same cycle of transformations again. The same laws of motion hold good whether we are dealing with visible lumps of matter or invisible molecules and atoms. This to-and-fro motion of the pendulum describes the vibrating atom. The atom possesses energy which is constantly changing from kinetic to potential, just as we saw in the pendulum. We have already seen that

the temperature of a body is due to the rate of vibration of its atoms. Hence we speak of the energy possessed by the vibrating atoms as *heat energy*. Heat energy is simply to-and-fro motion on a very small scale, but this is a distinctive form of energy. Let us follow out the transformation to heat energy.

We hold a heavy hammer over a piece of iron. The hammer while raised possessed potential energy, and when freed it exhibits kinetic energy, which disappears when the moving hammer strikes the iron. We find, however, that the temperature of the iron has been raised; its atoms have increased energy. If we multiply this effect by repeated blows, the increase in heat energy becomes most apparent. But gradually the temperature settles down again to normal. Where has the energy now gone? We may say that it has been dissipated or radiated away through space, but undoubtedly it still exists, although we may be quite unable to detect it even with the most sensitive apparatus.

It is quite clear that when the hammer falls upon a piece of iron and heats it, there has been merely a change in the form of energy; the initial energy has not been lost. This heat may be conducted away, in some measure, to other bodies with which the iron is in contact, but ultimately we find that the heat is radiated away into space. It is here that we fail to follow it; we can simply state that it has been added to the great reservoir of unavailable energy. We may picture it as going to increase the temperature of our planet in

the same sense as one might picture the sea-level of the world to be raised when we add a bucketful of water to the ocean.

I wonder how many of us, in our youthful inquiries, were puzzled with the fact that water, at atmospheric pressure, could never be hotter than 212 degrees Fahrenheit (100 degrees Centigrade)? I have clear recollections of puzzling over this fact, and thinking that if we still kept adding heat after water reached the boiling-point we *should* make it hotter. The solution of such youthful difficulties is very simple. When water steps over the line marked "boiling-point" it is no longer liquid water, but becomes *steam*. In other words, the molecules of water can hold on to one another up to a certain definite rate of vibration, but beyond that they cannot. They remain in the liquid state up to boiling-point, but above that they pass into the gaseous state. It is only at the free surface of the water that the molecules can escape, so the whole body of the water remains at boiling-point, and the application of further heat goes to free the molecules at the surface. Up to boiling-point we see a simple transference of heat energy from the source of heat—say, a fire—to the molecules of the water. After that a certain amount of energy seems to disappear; but we know that this energy is expended in driving the molecules apart, so that they no longer keep together in a liquid state, but become separated into the gaseous condition of matter. We know very well that this energy cannot

have disappeared in reality, and so we say that it has been transformed into latent heat.

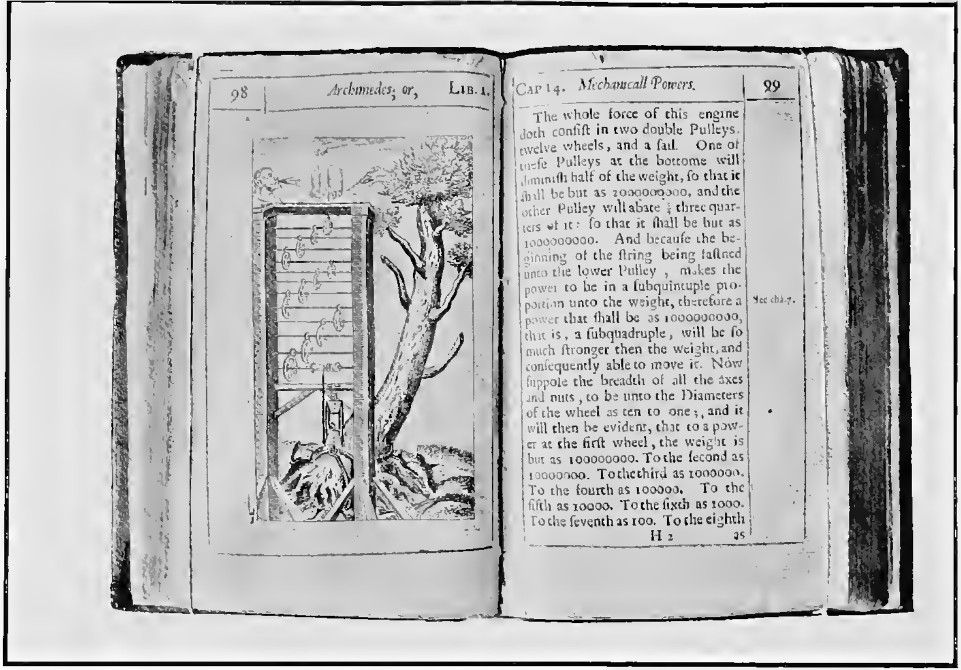
It is very doubtful if this term *latent heat* is a wise one; it would seem to signify a dormant form of energy, which really we cannot imagine. Surely the energy must exist still as motion in some form or other. We have the same misgivings in connection with potential energy. The energy in these cases cannot be asleep, as it were; there must surely be motion, although it is beyond our ken. If one reads the late Professor Tait's article on "Mechanics" in the *Encyclopædia Britannica*, one sees that he was impressed with the idea that motion must be locked up in some mysterious fashion in the condition we describe as potential energy.

It has been suggested that muscular energy is due to vibratory motion of the muscles. Indeed, it was pointed out by Dr. Wollaston, about a century ago, that muscles did vibrate when maintained in a state of tension. In the case of a muscular person supporting a heavy weight the vibrations have been detected by placing the observer's ear over the muscle, whereupon a definite sound is heard, the vibrating muscle acting in a modified manner as a tuning-fork. The physiological considerations arising from such facts are very interesting, but all that comes within our present province is to notice that in a contracted muscle there is a state of actual motion.

Where do we find no motion? From what we have seen in connection with the structure of the

atom, it is clear that the very existence of the atom depends upon the constant and rapid motion of the electrons within it. Think of the church analogy to which I referred at the end of chapter iii., and again at the beginning of chapter iv. There we see a mere handful of far-scattered dots or "full-stops" occupying the whole area of the church by keeping constantly on the move. Withdraw the motion and we can imagine the dots, instead of occupying the whole interior of the church, being gathered together in a small dust-pan. How much of the atom is really motion? Then again, if the electron, as has been suggested, is simply the æther—or on Mendeléeff's theory, the particles of the æther—in motion, how much of the fundamental electrons is motion? The very fact that energy is uncreatable and indestructible surely enables us to realise that it is a real thing.

We shall consider only one or two of the prominent forms of energy. We cannot pass over *chemical energy;* it is sure to be of interest to us, as we are continually seeing evidences of it. We know that many substances unite together in a very quiet and unobtrusive way. We have such a case when the energy of light waves falls upon the chemicals on a photographic plate and, unnoticed, disturbs the arrangements of the chemical atoms. But, on the other hand, we are aware of very energetic chemical combinations taking place within the cylinders of the modern petrol motor-car. We know that all explosions are due to a sudden rush of the chemical atoms in changing from one



98 Archimedes; or, LIB. I.

CAP 14. Mechanicall Powers. 99

The whole force of this engine doth conſiſt in two double Pulleys, twelve wheels, and a ſail. One of theſe Pulleys at the bottome will diminiſh half of the weight, ſo that it ſhall be but as 2000000000, and the other Pulley will abate ¾ three quarters of it: ſo that it ſhall be but as 1000000000. And becauſe the beginning of the ſtring being faſtned unto the lower Pulley, makes the power to be in a ſubquintuple proportion unto the weight, therefore a power that ſhall be as 1000000000, that is, a ſubquadruple, will be ſo much ſtronger then the weight, and conſequently able to move it. Now ſuppoſe the breadth of all the axes and nuts, to be unto the Diameters of the wheel as ten to one; and it will then be evident, that to a power at the firſt wheel, the weight is but as 100000000. To the ſecond as 10000000. To the third as 1000000. To the fourth as 100000. To the fifth as 10000. To the ſixth as 1000. To the ſeventh as 100. To the eighth

See chap. 7.

H 2 as

Uprooting a Tree by a Man's Breath

The above is the photograph of an old book entitled *Mathematicall Magick*, printed in London in 1648. The author says, "It is possible for any man to lift up the greatest oak by the roots with a straw, to pull it up with a hair, or to blow it up with his breath." It is apparent that the author has not calculated the time which would be required to supply the necessary energy in this way. I estimate it to be about six hundred thousand years.

set of molecules to other gaseous forms which occupy much more space. We have no difficulty in realising that there is such a thing as *chemical energy.* We should picture *chemical* energy as forcing the atoms from one molecule to another. What, then, should we think of *electrical energy?* Remembering that an electric current is the handing on of electrons from atom to atom, we should say that electrical energy forces the electrons away from the positive sphere of the atom.

In passing, it will be of interest to note the close connection between chemical energy and electrical energy in the ordinary battery. It will be remembered, from our consideration of electric batteries in chapter v., that atoms escape from the zinc plate into the liquid and there form new chemical combinations. And, further, that these escaping atoms leave behind them their detachable electrons, so that there is an accumulation of electrons upon the zinc plate. We saw that these accumulating electrons are handed on from atom to atom in the wire which connects the zinc plate or *element* to the carbon or other element of the battery. This electrical energy continues as long as the chemical changes proceed in the battery. We therefore say that in the battery we have chemical energy transformed into electrical energy, or in other words, the motion of the atoms in the battery gives rise to the motion of electrons along the wire. In an electro-plating bath we have the very reverse of this. We move the electrons along the wire circuit to one

of the electrodes in the liquid, and there we set up chemical action; atoms of silver or other metals contained in the liquid are deposited on the surface of an article acting as the leading-out electrode.

In the dynamo we see mechanical energy transformed into electrical energy, which in turn may be transformed into heat energy in the electric furnace, or the electrical energy may be transmitted to a distance and be converted once more into mechanical motion by means of an electric motor. The kinetic energy of a waterfall may be transformed into mechanical energy by means of the old-fashioned mill-wheel, and we might go on considering one series of transformations after another, but all such transformations are so obvious that we need not stop to consider them further.

We must remember that during all such transformations of energy there is some part of the initial energy lost, but lost only so far as our inability to get further work from it; no energy is destroyed. We therefore speak of the *conservation of energy*, and we call this one of the *laws* of Nature. We must remember, however, that these *laws* are of man's making, and are merely theories which appear to us to be perfect, and on this account we have elevated them to a higher platform than mere theories. Some day we may find our laws of Nature require amendments to be passed.

In the present chapter we have endeavoured to follow the transformations and transmission of energy in

matter; not only in connection with visible matter, but also with regard to the atoms and electrons contained in matter. But energy is not confined to these *forms* which we have been considering; it takes upon itself other forms outside of matter altogether, in the æther of space. That all-important medium is capable of transmitting energy over billions of miles, as we shall see in the following chapter.

Our position to-day is that we can resolve the Universe into matter—æther—and energy, but we cannot tell exactly what any one of these three entities is. We may explain matter away until we have nothing but electricity left, as we have seen in earlier chapters, but there still remains the question—What is Electricity?

In closing this chapter it may be of interest to tabulate the principal forms of energy. In addition to those forms mentioned in the following list, some might desire to add gravitational energy, cohesion energy, mechanical energy, muscular energy, and so on. These, however, may be placed under other forms already stated in the table on following page.

THE PRINCIPAL FORMS OF ENERGY.

Kinetic Energy	*e.g.*	*A flying bullet.*
Potential Energy	,,	*A raised clock-weight.*
Strain Energy	,,	*A tightened watch-spring.*
Chemical Energy	,,	*Gunpowder.*
Light Energy	,,	*Photography.*
Heat Energy	,,	*The Sun.*
Electrical Energy	,,	*The electric current.*
Magnetic Energy	,,	*A magnet lifting a piece of iron.*

CHAPTER X

WAVES IN THE ÆTHER

Waves on the surface of water—Transverse vibrations—Velocity of æther waves—What constitutes different "kinds" of æther waves—Transmission of energy by æther waves—Energy conveyed from the Sun to our planet—Light exerts a mechanical pressure—Why the tails of comets sometimes precede the heads—Store of energy within the atom—Tremendous energy of a rapidly moving body

As no one has seen, or ever will see, waves in the æther, that medium being itself invisible, it is evident that we must draw upon our imagination. Waves upon the surface of the ocean are familiar objects to all, but they do not provide us with a very good example of wave motion for the following reason. We often speak of some object having been washed ashore by the waves, as though the *waves* had brought the object from a distance. In reality it is the wind which has been the driving force. We shall therefore find a better example of wave motion in a still pond upon the smooth surface of which we can cause ripples.

We drop a piece of wood into the centre of the pond, and we see miniature waves spread outwards in circles, one circle following another at regular intervals. If the pond be a small one, the first wave does not take very long to reach the shore, while the

others follow in a regular march, but the piece of wood still remains at the centre of the pond. If we had placed corks at different points on the surface, the waves would not have carried a single cork any nearer to the shore; the corks would have merely "bobbed up and down." To speak more scientifically, we should say that the corks had vibrated in a transverse direction. By the word transverse we mean that they are turned across the path of motion, the word being derived from the Latin *trans*, across, and *versus*, turned. These are the kind of waves we have to deal with in the æther, and we therefore speak of them as transverse vibrations.

Looking at the ripples on the pond, it will be observed that the *wave motion* is travelling from the centre of the pond to the edge, while the vibrations of the corks, and therefore of the particles of water also, are up and down, or at right angles to the direction of the wave motion. All this is very simple, but unless the novice keeps the analogy of the pond before him he is apt to think that there is something mysterious in such a statement as—"light is transverse vibrations in the æther." The fact of the matter is that one thinks of this kind of wave motion more naturally than any other.

We have the to-and-fro motion of particles, like the swaying of people in a crowd, or, better still, like the movements of a long spiral spring. In this case we have states of compression and rarefaction, and in a long spiral spring one can see waves of motion passing

along it from one end to the other. As the to-and-fro vibrations are in the same direction as the wave motion, we speak of the vibrations as being longitudinal. Sound waves in the air, and in other substances, are of this nature. However, as all the waves in the æther are transverse vibrations it is only this one kind of vibration which concerns us at present, and we shall try, therefore, to keep before us the ripples upon the surface of a smooth pond.

In an earlier chapter the different æther waves were briefly mentioned. These were light waves, radiant heat waves, and electric waves. For convenience sake I spoke of these as different *kinds* of waves, meaning that they had different properties, but we shall see that they are really all of the one nature; they are all transverse vibrations, such as we see in a pond of water.

As all æther waves are of the same kind, and as they all travel with the same velocity, it is obvious that they can differ only in the rate at which they follow each other. In other words, the only difference between light waves and radiant heat waves lies in the distance between the successive waves. Suppose we had a float or plunger of some kind with a handle attached to it, so that we could conveniently move it up and down at the centre of our imaginary pond of still water. If we were to move the plunger up and down very slowly the waves would follow each other at some considerable distance apart, whereas if the movements of the plunger were rapid the waves or ripples would follow close upon one another's heels. Far more

waves would arrive at the shore in one minute when the plunger was moved rapidly. In order to compare the different sets or trains of waves we could measure the distance from the top or crest of one wave to the crest of the following wave. Of course it would make no difference if we measured the distance from the depression or trough of one wave to the trough of the next wave, or if indeed we measured the distance between any two corresponding points on neighbouring waves. This is what we call the *wave-length*. It will be observed that it has nothing whatever to do with the length along the front or ridge of the wave. By *wave-length* we simply mean the distance between two successive waves. Possibly some readers would be more inclined to call this the width or breadth of the wave.

When we vibrated the plunger rapidly we produced waves of short length. We see that there is a distinct connection between the rate or *frequency* of vibration and the length of the waves produced. The quicker we vibrate the plunger, the shorter will be the resulting waves. As the velocity of travel of all æther waves is the same, the connection between the frequency and the resulting wave-length is very simple. In one second of time every æther wave will have travelled a distance of 186,000 miles. Therefore if 1000 waves are set up by the vibrator during one second, the first wave will have travelled to a distance of 186,000 miles when the last wave is ready to start. In other words, there will be 1000 waves equally spread over a

distance of 186,000 miles. We do not require pencil and paper to calculate the wave-length in this case, for if 1000 waves occupy a space of 186,000 miles, it is obvious that each wave will occupy a space of 186 miles. We should say, therefore, that the wave-length in this case was 186 miles.

Some of the æther waves used in wireless telegraphy are measured in miles, while, on the other hand, æther waves as short as one two-hundred-and-fifty-thousandth part of an inch have been measured. It is, of course, quite impossible to realise the smallness of such dimensions, but we can appreciate the tremendous range of different wave-lengths existing in the æther.

We have seen that the whole difference between any one æther wave and another is in its length, or the spacing between the waves, and, of course, there must be a corresponding difference in the frequency or number of vibrations per second. It is marvellous that these æther waves which only differ in this way possess such very different properties.

Commencing with the longest æther waves, we find that these affect the detectors used in wireless telegraphy. We have seen that these *electric waves* may be spaced miles apart, but other electric waves of the same class have been produced as close together as six waves within one inch. Even this is very long when compared with the majority of æther waves. When æther waves only measure a few thousandths of an inch they produce heating effects, and we speak of them as waves of *radiant heat*. As long as waves are longer

than one thirty-thousandth part of an inch we call them dark-heat waves, for they do not affect our vision, but as soon as they step over that boundary line they do affect our eyes. They cause the sensation of red light when there are about thirty-four thousand waves to the inch. If the waves are still somewhat shorter—or closer together—they produce the sensation of orange colour; still decreasing in wave-length they produce the sensation of yellow, then green, blue, indigo, and when they have become so short that sixty thousand occupy one inch they produce the colour sensation of violet.[1] After that they cease to affect our eyes altogether, and we call them waves of *ultra-violet light*, signifying that they are beyond the violet rays.

Although these same waves of ultra-violet light fail to stimulate our sensory organs of vision, they very actively affect the chemicals upon a photographic plate. Because of their chemical properties these waves are often called *actinic* waves.

These æther waves are all conveying energy. Referring one moment to the pond analogy, it is obvious that if we expend some energy in giving the floating plunger an up-and-down motion, there will be energy transmitted by the resulting wave motion across the surface of the pond. Any corks or other floating objects will imitate the up-and-down movements of the plunger. We should say that the energy of the plunger was transformed into wave motion in the water, that energy was thus transmitted through the water to a

[1] More detailed particulars are given in Appendix III., at page 332.

distance, where it was transformed once more into kinetic energy, or energy of motion, in the moving corks. In the same way we speak of the transmitter in wireless telegraphy acting upon the æther ocean. The transmitting apparatus transforms the energy of moving electrons within it into wave-motion in the surrounding æther. This wave energy may be carried through the æther broadcast across the Atlantic Ocean, and, strange to say, an insignificant little detector on the far-distant shore receives sufficient energy to cause some change within it, and in this way signals are produced.

The transmission of heat energy from the Sun through the æther to our planet is obvious to all. It is interesting to note that it is possible to transform this heat energy directly into mechanical motion. We have a splendid demonstration in the large sun-motors which are used in some of the farms in California.

That the æther waves of ordinary light transmit energy is very obvious, for our sensory organs of vision are stimulated by them, while the chemicals upon a photographic plate are also affected. But the fact that these æther waves of ordinary light exert an actual mechanical pressure—just as the wind does—is not so apparent. Indeed, it is only within recent years that any experimental proof of this was obtained, for the pressure is very small—extremely small as compared with the pressure of the lightest breeze of wind, or of any slight movement of the air.

Nearly forty years ago Clerk-Maxwell, one of those

great mathematicians who must have been able to dream in mathematics, stated that such a force—or mechanical pressure—should exist in light, and he calculated what the actual pressure should measure. It is interesting to know that when experimental proof of this force was devised, the actual pressure was found to be of the order of magnitude that Clerk Maxwell had calculated it should be, so long before its discovery.

The demonstration was very simple. Very light discs of platinum were suspended in a small glass globe from which all the air had been exhausted. At this time the best means of producing a high vacuum was by means of the well-known mercury air-pump. A small amount of mercury vapour remains in the exhausted globe, so in order to get rid of this vapour the globe was subjected to an intense cold and the mercury vapour was frozen out. In this way the vacuum was made as perfect as it was possible. This was very important, for the demonstration would mean nothing unless the vacuum was very high, as the radiant heat waves would act upon any residual air and cause the disc to move, just as one sees the little vanes moving in the small radiometers so often exhibited in opticians' windows. In this case it is the heat waves which keep the small windmill revolving by a continual bombardment of gaseous molecules. The little windmill of the radiometer would not revolve if placed in the high vacuum which was used in this demonstration of the mechanical push of light.

Having got rid of any possibility of a molecular bombardment, the little suspended discs were exposed to light, and there could be no doubt they were being moved by the æther waves falling upon them. While this pressure could be observed and measured under these exceptional conditions, it will be understood that the pressure is so slight that we have no knowledge of it whatever in our every-day life; the effect is quite inappreciable upon any body placed in the great ocean of air around us.

If you desire to find out in what direction the wind is blowing when there is only an almost imperceptible breeze blowing, you hold up some very light object in the air. Why? Because it will offer a very large surface for the wind to act upon, while the pull that gravity has upon it will be very small. It is not difficult to imagine a breeze so gentle that its effect upon a whole bag of flour would be quite inappreciable, but which would become apparent if the individual particles of flour were falling as a fine rain through the atmosphere. Picture for a moment a steamer driving across the sea; the pressure of the wind keeps the smoke behind the steamer like a great tail. When the steamer turns round and travels in the opposite direction it is not an uncommon thing to see this tail of smoke preceding the steamer (see illustration facing page 150). This is exactly what we witness in the heavens in connection with comets. Away out in ætherial space we find comets making strange journeys, sweeping round the Sun and then disappearing

once more on a long journey through space, perhaps never to return. These comets have long tails, as seen in the illustration, and while they are approaching the Sun their tails behave in orthodox fashion and trail behind the body of the comet. But when the comet rounds the Sun and goes away from it, a very curious sight is witnessed. The tail appears to be "blown" on in front of the comet—just like the steamer's smoke. This fact that the comet's tail precedes its head when the comet is travelling away from the Sun has been one of the mysteries of astronomy. Of course, the Sun's gravitative force must be attracting the particles of matter forming the comet's tail, but it is apparent that some stronger force is driving them away from the Sun. Gravity is pulling the particles towards the Sun, and light is pushing them away from it, and it is apparent that in this particular case the light-push is greater than the pull of gravity. How can we account for this?

In the first place, we know that the particles of matter forming the tail of the comet are extremely small; their size can be calculated accurately. The Sun's gravitative pull upon these particles is correspondingly small, but the extent of surface of these particles is very great in proportion to their weight, so that the pressure of light is correspondingly great. We therefore find that Light is able to push these small particles away from the Sun with greater force than gravity can pull them towards it, and we therefore see why a comet's tail always points away from the Sun.

A few years ago a friend handed me an article which had just been published by an eminent astronomer. The subject of the paper was the comets, and this action of the comet's tail was simply explained as being "governed by the remarkable law that it must be turned away from the Sun." My object in mentioning this incident is to emphasise the statement, made in chapter i., that all the laws of nature are of man's own making, and that therefore it is no explanation to say that such and such a thing happens because of one of these laws. To state that the comet's tail is governed by a law that it must be turned away from the Sun does not satisfy the reason, but the theory of the mechanical pressure of light does.

No one can doubt that the æther transmits energy. When energy leaves the Sun it is carried by the æther for eight minutes before it arrives upon this planet. We know that the idea of "action at a distance" is now quite defunct. No one can reasonably think of one body acting upon another without the existence of an intervening medium. If this exploded idea had been true, there should have been no time at all required for the Sun to act upon our planet. We shall see later how this energy is transferred from matter to the æther and again from the æther to matter.

Once possessed with the idea of the electrons revolving within the atoms of matter at a prodigious speed, we picture an immense store of energy within the atom. In an earlier chapter we considered, in a somewhat rough-and-ready manner, the relationship

of energy, velocity, and mass. In the present case the electrons have not much mass to boast about, but what they lack in bulk they make up for in velocity. It is difficult for those not accustomed to science to realise the true importance of velocity as a factor of energy.

We have been referring repeatedly to the velocity of light. Of course light is not a material thing, but try and picture a small mass—such as the head of an ordinary pin—travelling through space with the same velocity as light. What amount of energy will the flying pin-head possess?

It is difficult to find any popular means of testing the energy of this flying missile, but possibly at some time or other we have seen machines for testing a man's strength. I remember one particular form which used to be in existence at country fairs. The would-be strong man was asked to test his strength in the following fashion. He had to strike an upright lever with a heavy hammer, and in so doing he caused an iron ring to be shot upwards on an upright pole. The more energy the man brought into play the higher up the pole did the ring go. I cannot recollect the exact height of these poles, but they would not exceed fifteen or twenty feet. Suppose our flying pin-head entered as a competitor at this "try your strength" demonstration. Judging from the size of the pin-head it should make a very poor exhibition, but because of its prodigious velocity it could certainly beat all comers. Suppose the ring to weigh one pound, we can easily

THE MECHANICAL PRESSURE OF LIGHT

In the upper photograph we see a comet with its magnificent tail. As a comet recedes from the sun its tail precedes its head, just as the steamer's smoke precedes it when travelling with the wind. In the case of the comet we believe this to be due to the mechanical pressure of light, as explained at page 148.

[The above photograph of a comet was taken by Prof. E. E. Barnard, Yerkes Observatory, U.S.A.]

calculate the height to which the ring would rise, provided all the energy of the pin-head could be transferred to the ring; we neglect the large proportion of energy dissipated as heat. Even if we suppose that the pull of gravity were constant at any distance from the earth, we find that the ring would go to an enormous distance. One mile might seem quite a decent record, but, under such circumstances as I have indicated, the ring would fly upwards for thousands of miles. If we take the decreasing value of gravity into account, we find that the ring sets off with so much energy that it would be shot off the planet altogether, never to return. Of course it would be utterly impossible to give a pin-head the velocity of light, but, by supposing an extreme case such as this, the importance of the velocity factor is brought out.

This analogy of the flying pin-head helps us to picture the enormous energy which must be due to the flying electrons contained within the atom. A pin-head is an enormous giant compared to an electron, but the energy possessed by the flying pin-head can stand a good deal of dividing. Besides, whatever energy is contained in one atom, must be multiplied enormously to give the total inter-atomic energy contained in a small piece of matter. For instance, if we desired to calculate how much internal energy was contained in a small cube of solid copper, measuring less than half an inch on each side, we should have to multiply the internal energy of one atom by one quad-

rillion, for there would be that number of atoms contained in the small piece of copper.

But surely all this about the internal energy of the atom must be purely hypothetical, for it is locked up within the atom and we cannot affect it in any way for the purpose of measuring its value. That is our position with the most of matter, but we have recently found a few forms of matter in which this inter-atomic energy is being unlocked by Nature. Some atoms are breaking up and allowing the flying electrons to escape. This, however, will be understood better when we come to consider radio-active bodies, such as the world-renowned element *Radium*. These radio-active bodies are of so much interest that they demand at least a chapter to themselves.

This chapter deals specially with energy in the æther, and all waves in the æther are often classified under the one heading *Light*. It will be of interest, therefore, to consider at greater length the question—What is Light?

CHAPTER XI

WHAT IS LIGHT?

Evidence against Newton's corpuscular theory of light—Electrons and light—Proof in favour of the electro-magnetic theory of light—Hertz detecting the electric waves—How the velocity of light is measured—How the wave-lengths are measured—Wasteful processes of producing artificial light—An ideal method in Nature

EVEN in our childhood we appreciated the fun contained in stories of fairies making collections of sunbeams, catching them and keeping them in stoppered bottles. Doubtless, before reading the earlier chapters of this volume, there was not a reader who did not know beforehand that light was simply waves in the æther. Or if their thoughts on the matter were not quite so definite, they knew at least that Light was not a material thing. At the present time it would be well-nigh impossible to ferret out any person who believes in Newton's corpuscular theory of light.

I remember, in my schooldays, wondering how Newton could call solemnly upon people to imagine particles so small that they could be shot off by the Sun and travel across ninety-three millions of miles, between the Sun and this planet, in eight minutes; eleven million miles in one minute. Indeed, as a

schoolboy, it seemed to me rather a joke that such a great man as Newton should seriously believe in the possible existence of such particles. Now we find that although Newton's corpuscular theory has been abandoned completely, there do exist corpuscles or electrons very similar to Newton's imaginary corpuscles. Further, we find that these small particles are shot off from all very hot bodies; even by the ordinary household lamp. Therefore the Sun is shooting off a continuous stream of these corpuscles or electrons, and we have seen that these particles can travel at a speed of sixty thousand miles per second within a vacuum tube. Had Sir Isaac Newton known these recently discovered facts he might have argued that it was possible for these flying corpuscles to attain a speed three times as great in the free vacuum of interstellar space, and that they travelled from the Sun to the Earth with a velocity of one hundred and eighty-six thousand miles per second. Such an argument as this might have seemed reasonable, but it could not have stood the test of modern experiments. We have positive proof that these flying corpuscles do not constitute *light*, and this we shall see from what follows.

We can experiment with these same flying electrons in vacuum tubes; it will be remembered that these electrons have been found to be identical, no matter from what source they are obtained. By experiment we find that a stream of electrons does not possess the properties of light. Light can be reflected, re-

fracted, and polarised—these are its distinctive properties—but the flying particles do not possess these properties. We cannot reflect, refract, or polarise them. The meaning of *polarising* light will be made clear in the next chapter.

Instead of being amused at Newton's corpuscular idea, we are bound to marvel at his genius in foreseeing the possible existence of particles of seemingly impossible dimensions, and capable of travelling at a prodigious velocity. Although we find that we cannot, by any artificial means, cause these electrons to travel faster than sixty thousand miles per second, we shall see when we come to consider the subject of Radium that it discharges electrons from within itself with a velocity of one hundred and twenty thousand miles per second. This seems to be getting suspiciously near the figures which represent the velocity of light. Although we can prove that these flying electrons do not constitute light, there is no doubt that had these electron velocities been known at the beginning of the eighteenth century they would have lent substantial support to Newton's corpuscular theory. In a later chapter we shall consider the effects caused by these flying particles reaching us from the Sun; but in the meantime we note that it can be asserted positively that these are not light.

We have no doubt whatever that light is a series of æther waves, and from what we have already seen in connection with moving electrons disturbing the æther and causing magnetic and electric fields in

it, we are quite prepared to accept the fact that the æther waves of light are caused by moving electrons.

In the preceding chapter we saw that the æther waves known as red light are so short, or, in other words, follow each other so rapidly, that thirty-four thousand of these particular æther waves occupy only the space of one inch. It will be apparent that whatever the object may be which is setting up such a rapid series of waves, that disturbing object must be vibrating at an enormous rate. When we were picturing the plunger setting up waves at the centre of a still pond, we saw that the faster the plunger moved up and down the more waves were formed in any definite distance or in any given time. Knowing the rate of travel of these æther waves and the number of waves per inch, a simple calculation shows us that the rate at which an electron must be vibrating to produce the waves of red light must be four hundred billion times per second. Of course the figures are beyond imagination, but all we can do is to picture an electron flying round and round an atom of matter, like a satellite around a planet, but making an enormous number of revolutions in each second of time. To say that one electron makes four hundred billion revolutions per second, and another six hundred billion, is only of use in enabling us to compare one velocity with another.

It must be clearly understood that all atoms of matter are made up of a number of electrons revolving

in regular orbits, and that we cannot in any way disturb these arrangements. But those free electrons which circulate round the atoms as satellites can be affected by outside forces. By applying heat to a body we hasten the speed of these revolving electrons. By cooling a body we cause these free electrons to revolve more slowly. In a lump of iron at ordinary temperature the motion of these electrons is disturbed by molecular collisions, so that the resulting rates of revolution cause very long waves in the æther. We call these heat waves, and every existing thing is radiating heat in some degree. To return to the very simple experiment of striking a piece of iron by a heavy hammer, we are able, by repeated blows, to cause the molecules to vibrate more rapidly, and this enables these revolving electrons to quicken their pace. Some of them soon reach a speed at which they set up those rapidly succeeding æther waves, which affect our eyes, and which it is usual to describe as *visible light*. By means of delicate thermometric instruments we can show that some of the electrons continue to revolve at the slower speeds and give rise to the æther waves which we label *dark-heat*. When a piece of iron has reached a white-heat, we can show by means of the spectroscope that its electrons are setting up the whole range of æther waves which make up the visible spectrum—and in addition to the dark-heat waves beyond the red of the spectrum we can show that other æther waves of ultra-violet light are also radiated from the glowing metal. It is clear,

therefore, that in the white hot metal we have electrons flying around their atoms at speeds varying not only from four to eight hundred billion per second, but some much slower and others much faster.

We have seen that it is the revolving electrons which provide the connecting-link between matter and the æther. It is truly marvellous that such infinitesimally small things as electrons—although distant ninety-three million miles from us, in the Sun, can affect us upon this planet. We can go still further and think of revolving electrons attached to atoms in the far-distant stars affecting us over a space of billions of miles.

All æther disturbances are caused by moving electrons. While light and radiant heat are caused by *revolving* electrons, the longest æther waves such as are used in wireless telegraphy could not be set up by electrons revolving in small orbits. They are produced by electrons surging to and fro in an electric circuit. We should have no difficulty, however, in appreciating the fact that all the different æther disturbances are of the same kind and only differ as regards their wave-lengths.

But some one might say that all this about light being an electro-magnetic disturbance of the æther is purely theoretical. A man, if he so desires, may say that the moon is made of green cheese, but no one will believe him, because he cannot bring forward any observed facts to support his theory. What facts can we bring forward to support this electro-magnetic theory of light?

First and foremost, we can definitely prove that light travels at the same speed as electro-magnetic waves. Indeed, scientists were sure of this fact before they could prove it experimentally. Long ago man found out by observation that light travelled with a velocity of 186,000 miles per second. How this observation was made will be explained a little later. But up to the year 1888 we could not measure the velocity of electro-magnetic waves—indeed we could only state that such things must exist. Nevertheless, at that time, mathematicians were able to calculate from electrical measurements what the velocity of such waves would be if they could be found. The result of these calculations was to bring out a velocity exactly the same as the observed velocity of light. Many people, who are not conversant with science, shake their heads at the idea of a mathematical proof, but if they were to make a serious study of the subject they would not do so.

In the year 1888 a brilliant young professor in one of the German universities found a means of detecting and measuring electro-magnetic waves in the æther. It was known at that time that an electrical discharge, such as the sparking between two electrified spheres, was of a to-and-fro, or oscillatory, character. These oscillations would set up waves in the æther, but no one could think of a means of detecting their presence. Who should be able to invent an instrument delicate enough to detect these seemingly un-get-at-able waves?

Dr. Heinrich Hertz, the distinguished professor already referred to, gave the answer. No elaborate apparatus was required, merely a simple loop of wire with a tiny break in it. At one end of his room Hertz had an induction coil arrangement producing electric sparks, and therefore, according to the theories of the mathematicians, producing electro-magnetic waves in the surrounding æther. Hertz went about the room with this simple loop of wire—something like a large wrist-bangle—in his hand. He found that sparks occurred at the tiny break in this loop of wire. It is only fair to other experimenters to remark that so far Hertz had discovered nothing new. Other scientists had made very similar experiments; notably Professor Silvanus Thompson, of London, as may be seen on referring to the *Philosophical Magazine* of September 1876.

At this date—a dozen years before the experiments of Hertz—Professor Silvanus Thompson had shown electric sparks occurring between two ordinary door-keys when placed close together and taken to some distance from the induction coil apparatus. But, when speaking of Hertz's work, Professor Thompson has said: "It never dawned upon me that these sparks were the evidence of electric waves crossing the space. That was Hertz's discovery. He did not go idly about the room noticing the sparks, but explored the positions where the sparks were to be detected, and holding his apparatus (the loop of wire) in the right position to detect them."

What we are interested in, at the moment, is the measurement of these waves. When Hertz found that he could detect these invisible electric waves, he soon adopted means of measuring them. He placed a great sheet of metal against the wall of his room, and then sent electric waves towards it so that the waves would be reflected back upon themselves. It is well known that when any kind of wave motion is reflected back upon itself, the reflected waves interfere with the original waves and cause what are known as stationary waves. Without going into details, we shall be content to note that points of interference are produced at which one wave quite neutralises the other. These are called *nodal points*, and it can be demonstrated that the distance between any two nodal points is exactly half one wave-length. We can therefore understand that when Hertz found two distinct places in his room at which his detector would not respond to the electric sparker or wave producer, he knew that he had found two nodal points such as just described. He knew, therefore, that the distance between these two places was exactly half the length of the electric waves which were striking the metal sheet and being reflected. By this means Hertz measured the length of electric waves.

Hertz knew the rate of electric oscillations in his wave-producing apparatus, so it was quite a simple matter to calculate how fast the waves would travel now that he knew how long the waves were. To make the matter quite clear let us return, for a moment, to

the pond analogy. By means of the plunger I might be able to set up a series of waves at the rate of two waves per second. I should know, therefore, that the distance travelled by the wave motion in one second would measure exactly the length of two waves. Some one measures the waves which I am producing and informs me that each wave measures exactly one inch, and so I am able to say that the wave motion is travelling a distance of two inches in one second. This, of course, is a purely imaginary case, but it will serve to illustrate how Hertz, knowing both the number of waves produced per second and the length of a wave, was able to calculate the rate of travel. He found that the velocity was 186,000 miles per second, thus verifying the mathematician's earlier calculations. In this way Hertz proved that electric waves travelled with the same velocity as waves of visible light.

The velocity of light had been determined more than two centuries before Hertz measured the velocity of electric waves. It would be difficult to explain the exact method without mathematics, but the following may give some idea. Nearly two hundred and fifty years ago astronomers noticed an apparent irregularity in the movements of one of Jupiter's satellites. Astronomers made time-tables showing where the satellite would be at certain times, but the satellite did not behave as it was expected to do. At one period of the year it was fully a quarter of an hour behind the scheduled time which it had kept six months previously. Here was a puzzle for

these astronomers. No one could suppose that the satellite fell off in speed at one time of the year and returned to its original speed six months later. Yet the fact remained that when this satellite disappeared behind its great planet, it was sometimes sixteen minutes and thirty-six seconds late in reappearing. It was well known that Jupiter was a very long way off from us—nearly five hundred million miles—but no matter how long light might take to travel from Jupiter to our Earth, surely it must always take the same time. It would do so provided the distance between Jupiter and the Earth was always the same. But these astronomers of the seventeenth century knew that this distance was not always the same. While Jupiter made one majestic march, in its far-distant orbit, around the Sun, the Earth made nearly one dozen complete circuits of its smaller orbit. Therefore at one period of our year we should be nearer Jupiter than we should be six months later. When we are at the farthest side of our orbit away from Jupiter, its light will have to travel the additional distance across our orbit, which it will not have to do when we are at the point of our orbit nearest to Jupiter. We all know that we are about 93 million miles from the Sun, so that the diameter of our orbit will be twice that distance, or 186 million miles. We have seen that these astronomers found by observation that Jupiter's satellite was *apparently* sixteen minutes and thirty-six seconds late, so it was quite clear to them that the light from Jupiter took that time to cross the Earth's orbit.

This time is practically equal to 1000 seconds, and during that time light has travelled 186 million miles, so we need not trouble about pencil and paper to calculate how far light will travel in one second. We have simply to strike off the last three ciphers of the 186,000,000 miles, and we find that light travels 186,000 miles per second. This is such an enormous speed that light appears to travel instantaneously from any one point upon our planet to another distant point on it.

It is interesting to know that Galileo tried to measure the velocity of light by covering and uncovering lamps at a distance, but, as we should expect, no result could be obtained. Nevertheless it has been found possible to devise methods of measuring the velocity of light by direct experiment. Without troubling about much detail, it is of interest to note the principle of one such experiment. An aperture is very suddenly opened and closed so that a beam of light can shoot out through the aperture, fall upon a mirror at a fixed distance, and be reflected back again to the aperture, where it can enter and be observed through an eye-piece. If light were transmitted instantaneously, the reflected beam could always re-enter the aperture, no matter how rapidly it was closed. A simple means of opening and closing the aperture very rapidly was devised. Picture a disc with a row of small holes cut in it around its outer edge; a toothed wheel is what is actually used. This disc is so arranged that the holes pass across in front of the aperture in succession. If

the disc is revolved at a high speed we shall have the aperture opened and closed with exceeding rapidity. If the light takes any time at all to travel from the aperture to the mirror and back again, we should find that at a certain speed of rotation of the disc the light wave would arrive back at the aperture at the moment it was closed. No light would be observed to enter the eye-piece when this was the case. Then if the speed of rotation be increased till the reflected light succeeds in entering the aperture by the hole which follows the one from which it escaped, it will be clear that it took the light just as long to travel from the aperture to the mirror and back again as it took the edge of the disc to travel the distance from one hole to the following hole. A simple calculation from the speed of rotation of the disc will give the time required for this very small movement of the disc. We therefore know how long it took the light to travel the measured distance between the aperture and the mirror. This turns out to be exactly equal to a speed of 186,000 miles per second. Several experimenters have devised other means of measuring the velocity of light, and all the results fall within 185 and 186 thousand miles per second.

Having satisfied ourselves that there is no guesswork about the stated velocity of light, it will be of interest to see how it is possible to measure the length of those waves which are said to be only about one thirty-thousandth part of an inch. One might think that this could only be understood by those who can think

in pure mathematics, but fortunately this is not the case. It will be remembered that Dr. Thomas Young, the first Professor of Natural Philosophy in the Royal Institution, London, was one of the pioneers of the electro-magnetic theory of light. One of his famous experiments was to show that two light waves could so interfere with each other that they caused darkness. Young took a very narrow beam of light of one colour—say, red—so that all the æther waves would be of the same length. He placed an obstructing screen in the path of this red beam, and only allowed the light to pass through two small holes placed very close together in the screen. Therefore from the back of the screen two small beams of red light proceed from two points very close together. The light from these is made to fall upon a white screen, and one would expect to find a patch of red colour made up of the two beams of red light coming through the two holes. However, Young found something more than that. The image upon the screen was made up of alternate red bands and dark bands, or in other words, bands of darkness. When either of the two small holes was closed the image on the screen was merely a patch of solid red, but as long as light passed through both holes these bands of darkness were present. Young used the result of this experiment as a proof of the wave theory of light. If Newton's corpuscular theory were correct, then two beams of luminous particles added together should only give an enhanced luminosity. In other words,

if you add something to something the result cannot be nothing. If, however, the two beams of light were not composed of material particles, but were merely wave motion in some medium, it was quite understandable that one wave might so interfere with another and produce these bands of darkness at their meeting point.

It was by means of this same simple experiment that Young was able to measure the wave-length of orange-red light. Picture a single train of waves passing through No. 1 hole and striking the screen at a point directly opposite it, while another train of waves passes through No. 2 hole and strikes the same point on the screen, which cannot, of course, be quite directly opposite the second hole. It is clear that the waves passing through No. 2 hole will have a very slightly longer distance to travel than those passing more directly from the first hole. If these two waves meet on the first dark band they interfere with each other, so the one wave must be exactly half a wave-length behind the other. Therefore the difference in the lengths of these two trains of waves will be exactly one half wave-length. Young found it possible to measure the very small difference in these two distances, and found it to be only one eighty-thousandth of an inch. This was, therefore, the measurement of one half wave-length of red light, so that the waves of red light measure one forty-thousandth of an inch. The other colours of the spectrum could be measured in the same way; a detailed list of these lengths will be found in Appendix III., at page 332.

We have pictured visible light as æther waves produced by electrons revolving around the atoms of matter. Our chief method of producing these short æther waves is by heating some substance to a high temperature. But despite all we hear of economical methods of artificial lighting, all our processes are ridiculously wasteful. Imagine a man manufacturing any useful substance, and for every ten pounds of the substance which he is making he produces at the same time ninety pounds of useless by-products, or substances for which he is to get absolutely nothing. No one has ever heard of such a wasteful manufacturing process, and yet that is a true analogy of what we do when we produce artificial light. Perhaps a better analogy would be to think of an employer of labour desiring to do a certain amount of useful work. From experience he finds that he requires to employ one hundred men to get the work done, but he is aware that the work he wishes done could be accomplished by ten of the men if they only knew how to do it. We burn a jet of gas in order to produce artificial light. We are seeking to set up æther waves of a certain length, but in doing so we produce only three per cent. of these waves and ninety-seven per cent. of waves we do not wish and could do very well without, as they are simply dark-heat waves. The hotter the body is which is setting up the æther waves the better is the percentage of useful waves, but even with electric arc lamps we can only attain an efficiency of ten or fifteen per cent.

In our methods of artificial lighting we are, in some measure, imitating the Sun, which produces thirty per cent. of visible light waves. Nature, however, is not wasteful; the remaining seventy per cent. of invisible æther waves set up by the Sun are required to supply us with heat necessary to maintain life upon our planet, and to produce chemical changes. If we could only imitate Nature as we see her producing light in the glow-worm, where practically the whole of the æther disturbance is in the form of visible light—no dark-heat waves being produced—we should be able to cause illumination on a grand scale. Referring to the luminosity of the glow-worm, Sir Oliver Lodge has remarked that if we could only obtain this secret from Nature, "a boy turning a crank could furnish sufficient energy to light an entire electric circuit."

We have seen how Hertz produced, detected, and measured æther waves by purely electrical means. It has become common practice, in wireless telegraphy, to set up these æther waves by causing the electrons to surge to and fro in an electric circuit. We have also realised that these waves only differ from visible light in being much longer waves. We must, therefore, hasten the motion of the electrons in order to produce the shorter waves of visible light; but that is our difficulty. The shortest æther waves we have been able to produce by electric oscillations are about one-sixth of an inch apart, whereas we must crowd no less than thirty thousand waves into one inch before they will

affect our visionary apparatus. Nature accomplishes this feat, but she does not employ a single to-and-fro surging of the electrons; she causes the electrons to spin round their atoms hundreds of billions of times per second. It is evident that we must find some means of giving the electrons this violent rotary motion before we can produce artificial light without the enormous waste we have at present.

It may not be clear to all how the present enormous waste arises in the production of light by means of heating a body. When we heat a body we cause a great disturbance among its molecules, and these incessant collisions between them prevent the free revolutions of the electrons around the atoms. Therefore we have electrons travelling at all speeds—a large proportion only attaining the speed at which dark-heat waves are produced, while only a very small percentage attain to the speed at which visible light is produced. What we want is to cause all the electrons to revolve at the high speed.

NOTE.—In dealing with the electro-magnetic theory of light I have not endeavoured to treat the subject from the historical point of view, but as this is of interest, I have given a short historical note in Appendix II. at page 328.

CHAPTER XII

MORE ABOUT LIGHT

The distinctive properties of light—The meaning of polarised light—A wild analogy—How we can show when light is polarised—Beautifully coloured lantern pictures from colourless slides—Experimental proof that heat waves and electric waves possess the same distinctive properties as visible light—How matter sets up æther waves—How æther waves react on matter—How some bodies reflect, and others absorb, light—A nonsense story—How tourmaline polarises light

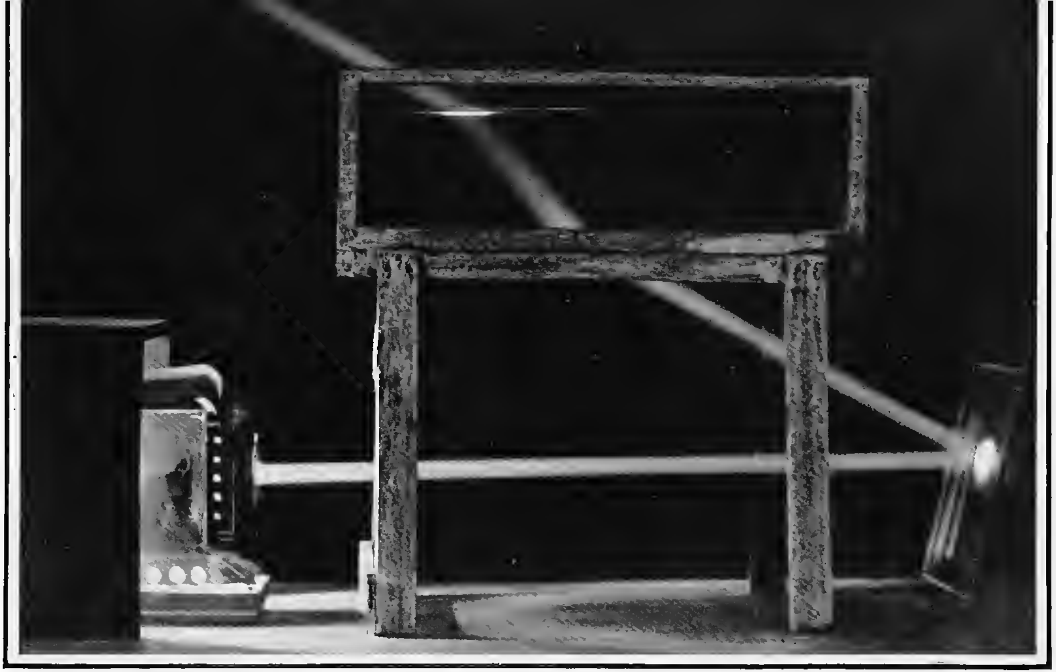
In the preceding chapter it was pointed out that there is no doubt whatever concerning the statement that dark-heat waves, and electric waves, are really invisible light waves, and that the sole difference is in their wave-length, or, in other words, in the distance between the succeeding waves.

We are so accustomed to some of the properties of ordinary light that we pass them by almost unnoticed. We see light falling upon objects all around us, and we do not stop to think that these objects are only visible to us because they *reflect* some of the waves falling upon them, and that these reflected æther waves enter our eyes. Every person is well acquainted with the fact that light can be reflected. A second property of light which even the most unobservant of us cannot

have failed to notice for ourselves, is that light can be bent out of its normally straight path. A straight stick placed at an angle—partly in water and partly in the air—looks exactly like a bent stick. This bending, or *refraction*, of light is shown very clearly in the photograph facing this page.

A third property of light is that it can be *polarised*. Although the name of this property seems rather mysterious, and possibly leads many people to imagine that the subject is a very difficult one, it is in reality very simple. The waves of the sea can only vibrate in an up-and-down or vertical direction, because they occur upon a flat horizontal surface. The æther waves, however, do not occur upon a surface, but are right inside the great æther ocean, so that "up-and-down" has no special significance for them. It is just as easy for æther waves to vibrate at one angle as another.

For some purposes it is convenient to picture the æther as a huge jelly. Picture an ordinary jelly such as is served for dinner or supper, but we shall suppose the cook has made us a very large and firm jelly for experimental purposes. If we stick two long pins—such as hat pins—into the jelly, placing one pin at some distance from the other, we find that any vibratory motion given to the one pin is imitated by the second pin. The jelly conveys the energy from the one pin to the other; we have set up wave motion within the jelly. It is immaterial whether the motion is up-and-down or from right to left, indeed it may be at any angle whatever.



Bending a Beam of Light

In the left-hand corner of the photograph may be seen a lantern sending forth a beam of light which, falling upon a mirror, is reflected upwards. The beam passes through a glass tank of fluorescent water, and then once more enters the air. The refraction of the light in passing from the one medium to the other is very apparent.

When ordinary light waves are produced by a heated body, we picture the disturbance being caused by electrons revolving around the atoms, and these will be lying at every variety of angle, so that it would be difficult to conceive all the æther waves vibrating in one particular direction only. The *polarising* of light simply means entrapping all the waves except those that are vibrating in one particular direction. The following analogy may help to make the matter quite clear :—

Suppose some wild creature was approaching a high wall in which the only gateway was a long vertical slot from top to bottom, just wide enough to let the creature go straight through. If this imaginary animal were staggering about from one side of the road to the other, being unable to stop this rapid side to side motion, it is clear that when it reached the narrow gateway the animal's progress would be barred completely. If, however, the imaginary beast's eccentricity consisted in its continually jumping up-and-down, but going forward in a straight line, the narrow vertical gateway would offer no hindrance to its passage. If a herd of such wild creatures were being driven towards a wall with a number of high narrow gateways, it is clear that only those animals which possessed the vertical jumping motion would get through. Therefore we should find on the other side of the wall a smaller herd of animals, but all moving vertically.

In this wild sort of analogy the animals are supposed to represent the wave motions of light. The obstruct-

ing wall with its vertical gateways represents a class of substances, the most notable of which is the crystalline gem *tourmaline.* A thin slice of this precious stone will act towards the waves of light just as the wall with its gateways acted towards the eccentric animals in our analogy. We picture only those waves which have a vertical motion getting through the tourmaline. Therefore the light which does get through is vibrating in one definite direction. We say that the light which passes through the tourmaline is *polarised.*

All these statements about the polarising of light may seem to be entirely imaginary. How can we tell that this has really taken place? We can see no difference.

Returning to the foregoing analogy for a moment, we might imagine the wall to be turned on its side, as it were, so that the gateway would lie in a horizontal position. Or we may make the analogy more complete if we imagine a high wall with a number of horizontal slots for gateways. Under such circumstances it would not be the animals with the vertical jumping motion which could get through; these would find their way barred completely. But the animals with the staggering motion would be able to stagger through these very wide horizontal slots or gateways. We have now adopted means of stopping the passage of both classes of eccentric animals.

If we, first of all, drive the herd, as before, through the vertical gateways, we allow only those animals with the vertical motion to get through. We drive these

jumping animals towards the second wall containing the horizontal gateways, and none of them can get through. The result is that we have no animals passing through the second wall. It is just so with tourmaline and light. We can produce vertically polarised light, and by passing that through a second slice of tourmaline, turned round on its side, as it were, or in other words, turned through a quarter of a revolution, we can block the way of these vertical waves and produce total darkness. It is customary to call the first piece of tourmaline the *polariser* and the second piece the *analyser*, but they are exactly similar, and only require different names to distinguish which piece of tourmaline is being referred to. There are other methods of polarising light, but all that we desire to note is that this is a distinctive property of light.

It may be remarked in passing that very beautiful colour effects may be produced upon the lantern sheet by means of polarised light. If the polariser and analyser are set so as to cut off all the light, we have a dark screen. If we then place a thin slice of mica, a well-known colourless substance, between the two polarisers, one would expect to see nothing. But the mica bends the waves out of their straight path, and it bends some waves more than others, according to their wave-length. Indeed it acts very much as a glass prism does when producing the solar spectrum. There is a spreading out of the different colours contained in the light. The analyser when turned round into one position blocks the way of certain

waves or colours, and when in another position it cuts off the passage of other waves. In this way we get different colours emanating from the lantern, according to the position of the analyser. Other substances act in the same way as mica, and the colours transmitted depend upon the nature of the substance, and also upon the thickness of the slice through which the polarised light passes.

I have seen wonderfully coloured pictures produced by perfectly colourless magic-lantern slides with the aid of polarised light. The images upon the slides are built up of various slices of different colourless substances. All are neatly pieced together, say, in the form of a many-coloured parrot. The slide is colourless, but when one sees the image upon the lantern screen it is difficult to realise that the picture is not produced by a painted or coloured slide. Additional interest is given by rotating the analyser, whereupon the colours completely change—the red tail of the parrot is now blue, and so on. The colours keep changing, of course, as the analyser allows the different wave-lengths to get through.

From the foregoing we have become familiar with the fact that light can be polarised. This property of light does not come before our notice in our every-day life, but there is another prominent property of light which does so. We cannot fail to observe that ordinary light falling upon a variety of objects is not all reflected back. It is apparent to the least observant among us that a white object reflects far more light

than a black object. What happens to the light which is not reflected back? It must be absorbed by the object upon which it fell. This absorption of light is a definite property, and one which is continually coming under our notice.

We can sum up the different properties of light under the titles—reflection, absorption, refraction, and polarisation. Do all æther waves really possess these same properties? They must exhibit these same phenomena if the statement is true that light, radiant heat, and electric waves are identical, except in their wave-length. We desire to see experimental proof of this statement.

First of all we shall compare radiant heat with light. We need scarcely trouble to call forward any witness to prove that radiant heat can be reflected just as visible light is. If one considers how it is that fruit ripens quicker when growing on a wall than it would do if merely on a tree, one is driven to the conclusion that the heat is reflected upon the fruit, so that it has these reflected heat waves added to the original heat waves.

If we desire experimental proof of the reflection of radiant heat waves we find many such experiments. If we go, in imagination, to the Royal Institution early in the nineteenth century, we find Sir Humphry Davy demonstrating this very point. He has two large concave mirrors of silvered metal, one of which is hung up over the lecture-table with its mouth downwards, while the second curved mirror lies on the table

mouth upwards. The one mirror is at the height of an ordinary ceiling, and is so arranged that it can be easily lowered to the table and raised again. A large iron ball is made red-hot and then hung up by a hook within this curved mirror, which is raised again. The heat waves are now reflected down upon the second mirror on the lecture-table, and after falling upon it they are brought to a focus, or, in other words, they are gathered together and meet at a point. If Sir Humphry Davy placed his hand at this point he could not hold it there for long, indeed if he placed any inflammable substance at this point it was immediately ignited by the heat. So much for the reflection of radiant heat. We agree that, as far as this one property is concerned, light waves and heat waves in the æther are of the same nature.

The second property we shall consider is absorption. The absorption of radiant heat is so common that it is difficult to think of any interesting experiment. Suppose we have the ground well covered with snow while the Sun is shining. We take two pieces of cotton cloth of exactly similar make, but one piece has been bleached white while the other has been dyed black. If we place these two pieces of cloth upon the surface of the snow so that the heat from the Sun may fall equally on both, we shall find that the snow underneath the black cloth melts long before that under the white cloth. It is obvious that the black cloth has absorbed the heat waves, whereas the white cloth has reflected them and thus protected the snow. We agree

that, as far as this second property is concerned, both light and radiant heat behave alike; they can both be absorbed by certain substances.

What about the next property—refraction? We shall have to make some laboratory experiment to demonstrate this. We know that a prism of glass will bend light out of its normally straight path, but a prism of glass is opaque to the waves of radiant heat. However, we can use a prism of rock-salt, as this substance allows radiant heat waves to pass through it. We first of all arrange a source of heat to throw a beam of radiant heat straight at a sensitive thermometer. The thermopile, or electric thermo-couple, makes a very suitable thermometer for detecting these waves of radiant heat. If we place the thermometer a little to one side so that the heat waves cannot reach it, it will register the normal temperature of the room. If we place a prism of rock-salt in the path of the heat waves we find that we can bend them round so that they fall upon the thermometer. We cannot see the waves, but we see the temperature of the thermometer rising. We have no difficulty in accepting the statement that, as far as this third property of refraction is concerned, both light and radiant heat are of the same nature. Almost every schoolboy knows that a lens will refract heat waves, bending them to a focus. Indeed, we used to speak of "burning glasses." I notice from the daily papers that a boy has distinguished himself by setting fire to the inside window blind of a shop,

the boy standing outside and concentrating the Sun's heat waves upon the blind by means of a magnifying glass. Fortunately the fire was got under before much damage was done, but it might have been otherwise.

There only remains the property of polarisation, and this may be demonstrated by means very similar to those used in the polarisation of visible light, the thermopile being used to detect the presence of the heat waves.

What about the electric waves, such as are used in wireless telegraphy? Do these possess the same properties of reflection, refraction, and polarisation? We have a very convenient method of detecting these electric waves. We may arrange that when they fall upon a "wireless" receiver an electric bell is set in motion. When we produce a torrent of electric sparks we set up electric waves in the surrounding æther, and these will spread out in all directions. If we place this transmitter or sparking apparatus within a copper box we shall entrap all the waves, but if we leave an opening in one side of the box some waves will escape. These will travel outwards in a straight line, but will gradually spread out just as light does. If the wireless receiver is within "the line of fire" the bell will ring. But we place the receiver in another copper box which also has an opening. We now place this box so that its mouth is just out of reach of the electric waves which shoot past it without entering. If we now hold a sheet of metal in the path of the waves, we find that by holding the sheet at a certain angle we can reflect

the electric waves so that they enter the receiver box and cause the bell to ring. There is no doubt that electric waves possess this property of being reflected.

Instead of using a sheet of metal to *reflect* the electric waves, we may place a prism in their path, and the waves in passing through the prism will be *refracted* or bent round so that they enter the receiver box. For this purpose we use a prism of paraffin wax, as it is more transparent to the electric waves.

Several experimenters have devised different means of showing that these electric waves are polarised; they are all vibrating in one direction. The simplest experimental proof of this is that they will pass through a special wire grid when it is held in one position, but when it is turned round, so that the wires are at right angles to the first position, the waves are blocked. The reason of this is apparent from our former consideration of polarised light. In the present case the waves are already polarised, so that the grid takes the place of the second piece of tourmaline, which is known as the analyser.

There can be no doubt in our minds regarding the statement that light, radiant heat, and electric waves are all of the same nature; we have definite experimental proof that their properties are identical. It is common practice to classify all these under the title of "Light," but this leads us to speak of visible and invisible light, and this seems paradoxical. We have associated the word light with our sensation of light, so that it seems ridiculous to speak of dark light. We

should be quite justified in classifying the three classes under the title of *electric waves*, but then that term is convenient to describe those waves set up by a wireless transmitter. Our best plan would be merely to call them all *æther waves*, some of which set up heat within the substances they fall upon, others affect our sensory vision, while others produce electric effects. When we come to consider the question of colour we shall see the advantage in not calling the æther waves light.

We are convinced that all æther waves may be reflected, absorbed, refracted, and polarised, but how do these things take place? The experimental proofs do not tell us the causes of the different phenomena.

Our thoughts naturally turn to the electrons, which along with the æther are the most fundamental things of which we have any knowledge. It is evident that a very heavy burden falls upon those tiny charges of negative electricity. We have seen that they are the stuff that atoms are made of. Electric currents and electric discharges are simply these tiny electrons in motion. We have also seen how the movements of these electrons give rise to magnetic fields, electric waves, radiant heat, visible light, and every variety of æther wave.

When electrons surge to and fro in a wire circuit they set up very long waves in the surrounding æther. When we have electrons surging to and fro in a wire we say that we have an *alternating* current of electricity in the wire. We give it this name to distinguish it from a *direct* or *continuous* current. In the latter

case the electrons are not surging to and fro, but are moving steadily along in one definite direction; we pictured them being handed along the line from atom to atom. When there is an alternating current in a wire we picture a rapid to-and-fro motion of the electrons, and we speak of having set up *electric oscillations* in the wire. The most rapid rate of electric oscillation that has been obtained was produced by means of induction coils, and is calculated to have been somewhere about five million vibrations per second. This seems a very high rate, and yet it is a long way from the four hundred billion vibrations per second required to produce visible light. The electrons giving rise to the æther waves which affect our vision are not surging to and fro, but are revolving around the atoms of matter. Those electrons producing the æther waves known as red light are going round their respective atoms four hundred billion times in every second.

Having become familiar with the idea of electrons disturbing the all-prevading æther, and thus giving us a definite connecting link between the æther and matter, it will be of interest to see how these æther waves react upon matter. It almost goes without saying that, when an æther wave falls on matter, it will be the electrons within the matter which are affected. These tiny electrons have helped us out of a big difficulty. Until we became aware of their presence we could not understand how matter was affected by æther waves falling upon it. Whenever

we discovered the existence of these tiny electrons all became clear, for an electro-magnetic wave will surely affect these small charges or atoms of electricity.

In the blazing Sun we picture electrons revolving around myriads of atoms of matter at a great variety of speeds. Why electrons go round some kinds of atoms faster than they do round others, we shall see later. These electrons in the far-distant Sun are producing a great variety of different wave-lengths in the æther.

First of all let us think of those long waves which we call radiant heat. When they fall upon a piece of matter on this planet they disturb the electrons within the matter. Suppose the matter happens to be a piece of metal. The electrons within the metal are already in a state of commotion before the æther waves fall upon them. But it is a disordered motion; some of the electrons are continually on the move from one atom to another. It is not unlike a party of very little children muddling through a square dance. An electron whirls round one atom, suddenly collides with another atom, whirls around it, and so on it goes wandering through among the atoms; there is no regular periodic motion, simply a commotion. The arrival of a series of æther waves, however, causes a definite disturbance, and we can picture those long æther waves very soon spending all their energy in opposing the motions of these roaming electrons, knocking them about from atom to atom. In this general commotion the atoms and molecules are thrown

into a state of greater vibration, and we say that the piece of metal has become heated. We see the radiant heat from the Sun, after travelling millions of miles in the æther ocean, being transformed into molecular heat upon this planet.

What about those æther waves which we call visible light? The Sun is also producing these, and when they arrive upon this planet they are received in different ways by different kinds of matter. In every case the motions of the electrons within the substance oppose the motions of the incoming waves. The electrons always tend to move in the opposite direction to the impulse of the wave. We need not trouble about the reason of this opposition, but any reader desiring to inquire into the matter should turn back to page 119, where we saw how electrons surging to and fro in one wire affected the electrons in a distant wire.

While we picture a general opposition, on the part of all electrons, to the invading æther waves, we take particular note that the really active opponents are those electrons which are capable of vibrating at the same speed as the incoming waves. We shall see the reason for this in the following chapter; all we wish to note at present is that these electrons succeed in stopping the incoming waves. But what happens to the electrons? The result depends upon whether the electron is able to hold its ground or not. If it is only loosely attached to its atom, the electron will be driven away and knocked about from atom to atom

they reflect waves of all the wave-lengths from red to violet we call them *white*.

We see that the meaning of *reflection* is something totally different from our former ideas of it. We have been accustomed to think of light being reflected from a surface, very much as an india-rubber ball will be sent back by an obstructing wall. Our ideas of to-day are different; we picture the incoming wave being stopped and a new series of æther waves produced by those electrons which succeed in stopping the waves. The moment the bombarding waves cease, the same moment do the electrons cease to revolve at the required speed to produce these regular vibrations giving rise to visible light. There are a few exceptions to this rule; in some cases the electrons continue to revolve for a lengthened period, and therefore emit light after the bombarding waves have been withdrawn. In such cases we say that the substance is *phosphorescent.* Luminous paints when exposed to daylight will continue to reflect light for some considerable time after they are placed in a totally dark room.

I can imagine some reader thinking that this new idea of reflection seems quite unnecessary, and that he would be content to continue thinking of light being reflected by simply rebounding from a surface. He could not explain phosphoresence upon this basis, and what is more important he could not reasonably explain the phenomena of colour, as we shall see when we come to consider that interesting subject.

No substance is capable of absorbing all the light waves which fall upon it; there are always a few electrons at least able to hold their ground against the incoming waves, and in so doing to send back or reflect some light. Hence there is no substance—no matter how black we may paint it—which cannot be seen when light falls upon it. I have some recollections of an amusing "nonsense story," telling of a scientist who devised a pigment which could absorb every light wave which fell upon it. This inventor annoyed a fellow scientist by playing a practical joke upon him. The inventor painted his friend's dog all over with this pigment, so that the dog became invisible, and only its brass collar could be seen moving about. The story went on to tell how the second scientist, on finding out the secret, painted the inventor's house all over with the same pigment while the inventor was from home. When he returned home he was very much alarmed to find that his house had disappeared during his absence. Of course the story is quite ridiculous, and even if the imaginary pigment had been able to absorb every æther wave falling upon it, the space occupied by the object would be seen as a patch of darkness.

A consideration of the foregoing story may be helpful to clear up some other points. Suppose the author of the story had been more of a scientist than his story proves him to have been. He would have taken the opposite extreme. He would have suggested that the practical joker succeeded in making the body of the

dog offer no obstruction to the æther waves, so that the light could pass freely through the dog's body. In other words, he would have succeeded in making the dog's body perfectly transparent, and it would then have been quite invisible. The author's difficulty would have been to suggest how the practical joker managed this. It is obvious that he could not apply a pigment for this purpose. The plan he suggested was simple, for the black pigment could absorb or stop the æther waves at the surface. A perfectly transparent pigment would accomplish nothing; the light would merely pass through it and be reflected by the dog's body as before. He would have to imagine some treatment that would affect the whole substance of the dog's body.

In most substances the light waves merely penetrate an extremely thin film of the surface, and there they are either absorbed or reflected. When neither of these results take place, the æther waves pass right through the substance, and we say that it is transparent to light. No substance is perfectly transparent; there are always a few electrons at least capable of taking up the rotary motion necessary to send back some of the æther waves. We know that some substances are wonderfully transparent. In the early days of plate-glass, my grandfather built a residence at some distance from his native town, and this was the first house in the neighbourhood to have plate-glass windows. When the house was finished, an old gentleman called and was shown into one of

the sitting-rooms. When my grandfather went in a little later he found the old gentleman with the collar of his coat turned up and a plaid drawn around him. He was under the impression that there was no glass in the windows, and it being winter-time, he feared getting cold. More than once I have found it difficult to tell if there was a sheet of glass between me and an object, but in such cases the light has been a subdued one. Even the air is not perfectly transparent.

In closing this chapter it may be of interest to sum up the ideas concerning the behaviour of æther waves when they fall upon a piece of matter. While we have been considering chiefly those æther waves which affect our vision, the statements relate also to radiant heat and electric waves.

In the majority of substances the æther waves are stopped by the electrons at the surface. If the electrons are driven away from their atoms in the act of stopping the waves, the waves are absorbed. If the electrons remain attached to their atoms the waves are reflected. In both cases the active electrons are those which can vibrate at exactly the same rate as the incoming æther waves. If a substance has practically no electrons able to exactly respond to the incoming waves, the waves are not stopped, they pass through the substance. There is, however, some opposition to the waves, and we find that they are retarded, losing about one-third of their original velocity, while in the medium.

In addition to the foregoing three distinct classes, there will of course be many substances which act in part like the one class and in part like another. Some substances are semi-transparent, or we might say semi-opaque. We use the word *opaque* for all substances which do not let the waves pass through them, whether they absorb or reflect the waves. It is common knowledge that certain substances absorb only part of the æther waves falling upon them and reflect the remainder, and so on.

The cause of polarisation will be apparent. Such substances as tourmaline possess electrons capable of vibrating in one definite direction. Hence the waves which get through such a substance are all vibrating in one particular direction, as are the up-and-down waves on the surface of the ocean.

What is of greater interest than all these phenomena is the fact that some substances are capable of reflecting only certain definite wave-lengths, thus producing the phenomenon of *colour*. This subject is of so much general interest that it demands a whole chapter.

CHAPTER XIII

THE EXPLANATION OF COLOUR

Why the subject of colour is apt to be confusing—Colour sensations—Ideas previous to Newton's discovery—Newton's ideas—How substances absorb definite wave-lengths and reflect others—The revolving electron—Astronomical analogy—How one electron sets up longer waves than another—Tuning-fork analogy—The waves forming the visible spectrum—Red objects may appear black in certain lights—A perfect colour-match and yet a very bad match—Some remarks on colour vision—An erroneous idea of colour-blindness—Heat-indicating paints

IT is surprising how so many people fail to grasp the real meaning of colour. Until recently we had only a partial explanation; we knew that certain substances absorbed certain æther waves and reflected others, thus causing the objects to appear coloured, but the explanation of this selective property of substances was not forthcoming. Why should one particular substance always absorb certain definite wave-lengths and not others? With the discovery of electrons there came a reasonable explanation of colour.

To the ordinary person the subject of colour always seems to be a troublesome one. There is really no wonder that it is so, for even those who do under-

stand the subject are content to speak of it in a most confused manner. We fail to make a proper distinction between *colour* and *light*. We say that at the close of the seventeenth century Sir Isaac Newton discovered that ordinary white light was a mixture of all the colours of the rainbow, and so we speak of white light as a bundle of coloured rays. We think of one substance absorbing certain colour rays and reflecting others.

This manner of speaking is considered quite orthodox, but I feel sure that it accounts for a great many of the difficulties connected with the subject of colour. We have really no right to call white light a bundle or mixture of colour rays; it is a stream of æther waves of various lengths, and nothing more. Perhaps an analogy will make the matter clear. On the battlefield a flying bullet strikes a soldier and produces the sensation of pain within him. The flying bullet and the pain are two totally different things; no one could ever think of calling the flying bullet a pain, and yet that is just the sort of thing we are doing in connection with light. In ordinary sunlight we have nothing but æther waves of various lengths, and when these fall upon our eyes they produce certain sensations of colour. If they all enter the eye they produce a certain sensation which we call "white." If we screen off some of the waves and allow only waves of certain definite lengths to enter the eye, then we have a definite colour sensation according to the lengths of the waves admitted. We have really no

right to speak of these æther waves as colours or colour rays. The æther waves, like the flying bullet, strike something and cause a sensation; we must clearly differentiate between the sensation and that which gave rise to it. We can only speak of a luminous body sending out colour rays in the same way as a poet might speak of the enemy's cannon pouring forth pain and death. The question of colour should only concern us when we are studying the senses; the æther waves alone concern us when we are dealing with what takes place outside of ourselves.

Before Newton's time people believed all light to be naturally white. When it was passed through a piece of red glass they thought that the light was dyed red by the glass. When white light fell upon a green object they pictured the light to be made green by the object, and so on. Of course, even Newton believed light to be a material thing, composed of infinitely small particles or corpuscles. It was a long fight between Newton's corpuscular theory and the suggestion that light was merely wave-motion in the æther.

Newton, however, upset all the existing ideas concerning white light being a simple thing. By passing a beam of ordinary sunlight through a glass prism he was able to produce all the colours of the rainbow. Instead of the beam of ordinary white light emerging from the other side of the prism there came forth distinct colours, spread out in the form of a band. It was not supposed that the light had been

coloured by the glass, as the glass was colourless. There could be no doubt that the glass prism had merely separated or sorted out the different constituents of sunlight. This was, indeed, a great discovery; we are apt to lose sight of its importance. How much knowledge has been gained by analysing light in this manner will be shown when we come to consider how the spectroscope has advanced our scientific ideas.

It will be clear that we have two separate things to consider in seeking a full explanation of colour. We must deal with the æther waves themselves, and then with the sensations resulting from the impact of these waves on the retina of our eyes.

First of all, we wish to know how it is that substances possess this selective property of absorbing certain wave-lengths. We have seen, in a very general way, from the preceding chapter how the electrons behave under the impact of æther waves. There is a general reaction—all the revolving electron satellites within the substance oppose the incoming waves, but the really active opponents are those electrons which happen to be able to vibrate at exactly the same rate as the incoming wave. But why should one electron be able to vibrate or revolve at any one particular speed better than another? As all electrons are identical—no matter from what source we withdraw them—it is clear that the determining factor does not lie within the electron itself. The atoms of the different elements, however, are very different from

each other. We know, for instance, that a uranium atom is nearly two hundred and forty times as heavy as a hydrogen atom, and although gravitation has nothing to do with the attraction between atom and electron, we can imagine, from what we have seen in the earlier chapters, that the varied constructions of the atoms will be one of the determining factors in the distance between the atom and its satellite. There are other forces acting upon the electron in addition to the attractive and repulsive forces within the atom. There is the influence of surrounding atoms; indeed the forces which determine the position of the natural or periodic orbit of a revolving electron are extremely complex. For our present purpose it is sufficient to know that each kind of atom, or in other words, each elementary atom, has a definite orbit which its electron will pursue, if free to do so, when it is set in motion.

We picture some electrons revolving in close proximity to their atoms, while others revolve round their atoms at a comparatively greater distance. In all cases the actual distance can only be measured in millionths of an inch. But we picture these electron satellites to be revolving around their atoms at various distances, just as we find the planets doing on a very grand scale in the heavens. The planet Mercury revolves around the Sun at a distance of about thirty-six million miles, while Neptune makes an immensely greater circuit at a distance not very far short of three thousand million miles from the Sun. The orbits

of the other known planets lie between these two extremes.

But what does it matter whether an electron describes a small or a large orbit around an atom? It will make a very material difference, because the size of its orbit—or in other words, the distance it is from its atom—will determine the velocity with which it will travel. We may understand this better if we look once more at the movements of the planets around the Sun.

There is one fact about the motions of the planets which, I think, is very often overlooked by the general reader. The farther away a planet is from the Sun, the slower does the planet move. Of course the farther away a planet is, the larger circle it has to describe. Neptune takes one hundred and sixty-four years to make one journey around the Sun, while our Earth only takes one year. But that is not the point I refer to. Our Earth is travelling through space at a speed of a little more than eighteen miles per second, while Neptune is going along at a pace of only about three miles per second. In other words, our Earth is going six times as fast as the outermost planet Neptune, while the Sun's nearest neighbour, Mercury, is forging ahead at a speed of twenty-nine miles per second against our eighteen. It will be understood that I am referring to these movements of the planets only by way of analogy; the forces which govern the velocities of the planets are quite different from those which govern the velocities of electrons.

From the foregoing it will be clear that electrons which make a rapid journey around a small orbit will set up short waves of great frequency in the æther—such as the waves we call ultra-violet light. Other electrons which revolve more slowly around their larger orbits will produce long waves of lower frequency—such as the waves we call radiant heat. In orbits between these two extremes electrons will revolve at speeds which produce all the variety of waves which give rise to visible light, from the longer waves producing the sensations of red to the shorter ones producing the sensation of violet.

We are now in a position to understand how some substances absorb certain definite wave-lengths. We see that the electrons have natural periodic motions according to the kind of atom to which they act as satellites. We may take it for granted that an electron pays little attention to an incoming æther wave unless the wave happens to be swinging to and fro at the particular rate at which that electron would naturally move. I think we shall do well to consider a well-known lecture experiment by way of analogy.

If we have two sets of tuning-forks of varying pitches mounted on sounding-boards, and if we place the two groups at a little distance from each other we find the following results. When we cause one particular fork in the first group to vibrate—by drawing a violin bow across it—we find that if there is an exactly similar fork in the second group that fork will commence to vibrate also. The other forks which

cannot vibrate in sympathy with the incoming air waves remain practically silent. It is always of interest, when performing this experiment, to stop the first fork vibrating, whereupon the distant fork is heard to continue sounding out the same note on its own account. A fork vibrating at a certain number of vibrations per second sets up air waves of the same frequency, but these only affect another fork capable of vibrating at the same rate. In the same way we find that a revolving electron, in a luminous body, sets up definite æther waves, and these only affect distant electrons capable of revolving at the same rate. In the case of the electrons we have already seen that the motions oppose each other, and the energy of the incoming wave is spent. But if the opposing electron can remain attached to its atom, the electron will behave like the tuning-fork in our analogy, and will set up æther waves on its own account, and thus radiate light. This is our present idea of the reflection of light.

There is really nothing mysterious in the foregoing idea of the electron stopping an æther wave and setting up a similar wave. The tuning-fork behaves in a similar manner towards air waves. When an air wave strikes the silent fork the energy of the wave is expended in setting the fork in motion. The incoming air wave is stopped, but the fork having been set in motion continues to set up other similar air waves on its own account. Of course we must not press the analogy too far, for in the case of the forks we are

ducing waves and two octaves of ultra-violet light possessing active chemical properties.

To return to the question of colour, we have to deal only with the one single octave representing the visible spectrum. The seven notes of this octave represent the seven different wave-lengths which produce the colours of the spectrum—Red, Orange, Yellow, Green, Blue, Indigo, Violet. For our convenience we may call the waves by the first letters of the colours which they produce—R, O, Y, G, B, I, V.[1]

We may picture a luminous body, such as the Sun, to be a great myriad of atoms of different elements, and we picture electrons revolving around each atom. Among these revolving electrons there are those setting up the seven wave-lengths with which we are going to deal. These waves fall upon a piece of substance upon this planet. If that piece of substance happens to contain a similar series of electrons, then they will in turn send out similar æther waves, and we say that the substance reflects white light. If, however, the substance only contains electrons capable of responding to R waves, it will only set up R waves. By the word *responding*, as used here, I mean electrons which can revolve at the same rate as the incoming wave and remain attached to their atoms. If a substance only sets up R waves when the whole series from R to V waves fall upon it, then only that part of

[1] We have been accustomed to think of seven colours, but it should be understood that this number is merely arbitrary; recent text-books omit the Indigo. See footnote, p. 332.

our vision apparatus which is sensitive to R waves will be affected, and we shall have the sensation of red. For convenience sake we say that the object is red, but we are well aware that the colour does not reside in the object. All the other wave-lengths are reflected or absorbed in the same way.

We cannot expect a substance to reflect a wave-length which does not fall upon it. In the surface of the cover of this book there are electrons capable of responding to R waves. When white light falls upon it we have R waves reflected to our eyes, and we say that the cover is red. If we view the book by the light of a mercury vapour lamp[1] we do not see it red, because there are no R waves in this particular light to stimulate these electrons. We see the cover practically black or dark brown, because the electrons in its surface cannot respond to the waves falling upon them. This is an extreme case, but we can find the same thing in everyday life.

We shall suppose that in the evening a lady buys a ribbon to match her hat. She is very pleased to obtain such a good match to the colour, but in the morning she has reason to regret her purchase; the ribbon and the hat are quite different tones of colour. Then she remembers that she bought the ribbon by

[1] The mercury vapour lamp is a long vacuum tube with a small bath of mercury at each end, covering the ends of the wires, which are sealed in the glass. An electrical discharge has to pass from the one mercury bath to the other, and in so doing it vaporises some of the mercury, and this discharge passing through the mercury vapour gives a wonderfully powerful light, but of a most disagreeable and sickly colour, the red-producing rays being absent.

artificial light. The difficulty arises from the fact that the artificial light did not contain all the variety of wave-lengths contained in daylight. In the evening the ribbon and the hat were tested only with certain wave-lengths, and there were electrons in both objects which behaved in exactly similar fashion under the influence of these waves. In the morning, however, the two objects were subjected to some other wave-lengths which found responding electrons in the one object and not in the other, and consequently the two objects appeared to be quite different in colour.

It may be helpful to add a few remarks here about our colour vision. Until recently the general idea was that there were three nerve-endings in the human eye, one of which was sensitive to what we have been calling R waves, and when stimulated producing that sensation which we term red; another nerve-ending was supposed to be sensitive to G waves, producing the sensation of green; while the third was sensitive to V waves, and gave rise to the sensation of violet colour. It is a curious fact, although there are seven wave-lengths or colours in the solar spectrum, we find it sufficient as far as our senses are concerned to suppose only three individual sensations, all the other colour sensations being merely combinations of these three primary sensations. For instance, R waves and G waves combined in certain proportions give us the same colour sensation as the Y waves of the spectrum do. In other words, when both the red and green sensations are simultaneously stimulated we have

that sensation which we call yellow. If the same two primary sensations are excited, in different degrees from that which we have just supposed, we have the sensation of orange colour. Then again, if the green and violet sensations are simultaneously excited we have the colour sensation of blue. All other colour sensations are merely different combinations of these.

This theory of colour vision, which we have been considering, was suggested by Dr. Thomas Young (London) and Professor Helmholtz (Berlin), and has therefore been known as the Young-Helmholtz theory. The theory still holds good as far as the sensations are concerned, but our present idea is that there are no special nerve-endings as was supposed, for we fail to find these in the retina of the eye. We believe that the action of light in the eye is a purely chemical or photographic one, although we fail to detect the supposed chemical change in the human eye. In the eye of the frog we do find a visible chemical action. There is a chemical substance exuded over the retina, and this has been named *purpurine* because of its purple colour. The action of light upon this purpurine is to bleach it white. Probably there is some equivalent chemical substance in the human eye which does not happen to show any visible change. If we imagine some substance having three different constituents, one constituent having electrons which respond to R waves, another with electrons responding to G waves, and the third sensitive to V waves, we can afford to dispense with the three special nerve-

endings. In some unexplained way these electrons, when set in motion by the incoming æther waves (light), may produce chemical changes, which in turn produce the nerve impulses that give rise to those colour sensations which we experience.

As we are not concerned so much with the physiological side of the subject we need not trouble further with colour sensation, but there is just one point I should like to remark upon. I have found many people harbouring an erroneous idea of colour-blindness, and the reason of their error is not far to seek. They have been told that a colour-blind man sees dark-blue in place of red, and that pink appears to him to be sky-blue. This seems to some people to be rather a crossing of colour sensations than a blindness, but that is not so. The statement referred to is quite correct provided the red colour is a compound colour such as crimson. A so-called crimson object reflects two classes of æther waves —those producing the sensation of red, and those producing the sensation of blue. If a man is colour-blind to red, then only the blue sensation will be stimulated. The same holds good with the compound colour pink, which is practically a very pale crimson. But the same man, if shown the solar spectrum upon a screen and asked to point out the colours, will not see blue at the red end of the spectrum. He will describe the lower end of the spectrum as merely a defect of light.

Considering only what takes place outside of our-

selves, we have quite a reasonable explanation of colour. It is here that we see the benefit of the new idea concerning the reflection of light. In the foregoing we have supposed white light to be falling upon the substance, so that its electrons were bombarded by the whole range of æther waves constituting the visible spectrum. But suppose that the luminous body is only emitting one particular wave-length—say, R waves—then no matter how varied the capabilities of the electrons contained in the substance upon which the light falls, it will only be those electrons which can respond to R waves that will reflect light. In other words, we say that when red light falls upon any substance, that substance can reflect only red light; if the object contains no electrons capable of responding to red light, then the object appears black.

In the same way, if R waves are not present in the light falling upon the object, there cannot be any R waves reproduced by that object. We have referred to this fact already in connection with the mercury vapour lamp. In its light we see no so-called red objects. I have seen a dinner-table beautifully decorated with bright red flowers, the effect being most pleasing when viewed by ordinary electric light. When the light was switched off and the room was lighted by a mercury vapour lamp not a trace of colour remained in the red flowers; they were a most funereal black. Not a single red object could be seen in the room; some were black, but others appeared dark-blue for the reason mentioned in connection with

colour-blindness. The substance of the flowers was still capable of setting up R waves, but as no R waves fell upon it the electrons lay dormant, if, indeed, we can ever speak of an electron being at rest. The moment the ordinary light was switched on again the electrons responded to the R waves, and the flowers appeared as red as ever.

A very simple demonstration of the same phenomenon may be made without any trouble. A mixture of methylated spirits and common salt may take the place of the mercury vapour lamp. When this mixture is ignited there are practically no R waves emitted by it, the light being entirely composed of Y waves. A pure red appears perfectly black. The light of the mercury vapour lamp is of more interest in one way; a crimson object appears blue, and we therefore see it very much as a man who is colour-blind to red would see the crimson object.

Picturing the electron revolving around its atom and setting up æther waves of definite length (definite colour), we can imagine readily that if the atom itself were caused to vibrate at an abnormal speed, the revolutions of the electron might be very materially affected. We have evidence of such occurrences. For instance, a certain chemical compound—the double iodide of mercury and silver—appears yellow at normal temperatures. If we hasten the vibrations of its atoms by increasing the temperature to about 110 degrees Fahrenheit (45 degrees Centigrade) the substance appears red. Another substance

appears scarlet at ordinary temperatures, but practically refuses to send out any æther waves of light at a high temperature; the substance then appears black. On cooling, the substance again radiates R waves. These substances are used as heat-indicating paints, and some interesting experiments may be made with them. For instance, if a sheet of paper is coated over with the yellow paint, and then placed in front of a fire or other source of heat, the paint will very quickly change from pale yellow to red. If any object is placed between the source of heat and the painted screen, a shadowgraph of the object is obtained, as the æther waves of radiant heat do not get at those parts of the screen which are sheltered by the intervening object. The demonstration would be more effective if a dark source of heat were used, and the shadowgraph produced in the dark. It would then be clear that the image was produced by the long dark-heat waves which are beneath our range of vision.

In the present chapter we have seen how the electrons within a substance reflect or absorb æther waves and then affect our colour sensations. We have not seen how it is that a glass prism separates these æther waves and spreads them out in the order of the spectrum. As already indicated, we have gained so much knowledge by means of this method of analysing the æther waves that it will be of interest to devote a separate chapter to the ideas obtained from the spectrum.

CHAPTER XIV

IDEAS OBTAINED FROM THE SPECTRUM

How to produce a spectrum—The action of glass upon the æther waves—Why the direction of the waves is altered—Analogy of soldiers marching—How the different colours are separated—The part played by electrons in transparent substances—The construction of the spectroscope—Watching the spectrum being gradually built up—How dark lines are produced in the spectrum—What these tell us—Bright lines—The chemistry of the Sun—Newton never noticed the dark lines in the solar spectrum—The small quantity of matter which the spectroscope can detect

THE solar spectrum has been referred to repeatedly in the foregoing chapters, and every person is conversant in some measure with its appearance. Even those who have never had an opportunity of looking through a spectroscope have seen a spectrum at some time or other upon the floors or walls of their dwellings. These spectra may have been produced by a beam of sunlight passing through a triangular piece of glass suspended from a gasalier, or by the sunlight striking a cut-glass bottle, or perhaps the bevelled edge of a mirror. If any one has failed to observe these chance spectra, he must at least have seen the solar spectrum upon a gigantic scale in the rainbow when the Sun shines on falling rain. Most of us have come across

coloured representations of the solar spectrum at some time or other.

Small pocket spectroscopes may now be obtained from opticians at a cost of about ten shillings, so that the amateur may examine the spectra of different elements for himself. If any one cares to take the trouble to arrange that a beam of sunlight enters a darkened room, then by holding any cheap glass prism—one off an old gasalier will do—at some distance from the slot in the dark shutter, and at right angles to the slot, one may form a beautiful spectrum upon a sheet of white paper. That is what Sir Isaac Newton did about two hundred and fifty years ago. We wish to see how this separation of the different æther waves is accomplished by the prism.

First of all we must note what happens when æther waves fall upon any piece of ordinary glass, such as a window pane. We shall deal with the æther waves forming a beam of sunlight. We find that if these æther waves come straight at the glass plate, or in other words, if they strike the glass at right angles to its surface, the waves go straight through and continue in a straight line. But we saw in an earlier chapter that æther waves are retarded while passing through glass; indeed their speed is reduced by some 60,000 miles per second. Wherever æther waves meet with electrons the forward motion of the waves is retarded. In interstellar space they meet with practically no electrons, so that they maintain a speed of 186,000 miles per second while they are

crossing the billions of miles separating us from far-distant stars.

This retardation of æther waves when passing through glass does not produce any apparent phenomenon when the waves go straight at the glass and enter it at right angles to the surface. But picture a beam of light striking the glass at an angle and see what happens. The favourite analogy is to imagine a line of soldiers as representing the wave front. Picture the soldiers marching well in line and approaching a patch of rough country; they are not going straight at it, but approaching it in a slanting direction, so that the soldier on the extreme right will enter the rough country first. His walk will be impeded, and we find that his pace across the rough country is only two miles per hour as against three miles in the open country. As each soldier enters the rough country his speed is similarly reduced, but it is apparent that the soldiers on the extreme left of the line will have continued longer in the open country than the others. Hence they will have maintained their full marching pace of three miles per hour longer than those who first entered the rough country. By the time the soldiers on the extreme left enter the rough country those at the other end of the line will have fallen behind the original line of march, so that the direction of the line of march is now altered. It is just as if the soldiers had got the command of "Right Turn!"

Once in the rough country they all march again in even line, but notice that they are still marching in a

slanting direction, though not at quite such a sharp angle as before (see diagram *B*, page 214). Looking at the diagram, one can easily see that the soldiers on the extreme right will be again the first to cross the boundary line. They will be in the open country first, so that they will get in advance of the others who are later in leaving the rough country. What has taken place is exactly the converse of what occurred when they entered the rough country, so that the line of march has been swung round into the same direction as it was in originally. This is represented in the diagram *B*. In the foregoing analogy we see the æther wave-front striking the glass at an angle and being bent round on entering the glass, while it regains its original direction on leaving the glass.

We have been picturing a straight patch of rough country with its two boundary lines parallel to one another, as in first diagram. Suppose, however, that the patch of rough country is of an irregular shape, such as represented in the other diagram *C*, so that the second boundary line is not parallel to the first, what will happen ? It is evident that the man who was the first to enter the rough country will be the last to leave it, so that the line of march will be bent still further round. It is just as though there had been a second command of "Right Turn!" This will be apparent from the diagram, which not only represents the soldiers marching through a patch of rough country, but equally well represents a beam of light passing through a glass prism. The æther

wave is bent round both when entering and leaving the glass.

If the beam of light which we pass through the prism consists solely of R waves, we shall find that the beam has not been bent very far from its original direction. Suppose we mark the letter R at the place upon the screen whereon those red-producing waves fell. If we then try a beam of G waves, leaving the screen and prism just as before, we shall find that these waves are bent further round, so that the patch of "green light" falls further along the screen. Repeating the same experiment with violet light, we find that these waves are bent still further round, so that they form a violet image at some distance beyond the green. Had we tried orange and yellow lights we should have found them to fall between the red and the green, while blue and indigo would have taken their places between the green and the violet. It is in this way that the spectrum is formed.

We might extend the analogy of the soldiers, and picture seven different companies all approaching the rough country in one line; they can all march equally well in the open country. The men in No. 1 company do not find the rough country so great an obstacle as the men in No. 2 company find it, so that the line of march of No. 1 company is not altered to the same extent as that of No. 2. These two companies will be travelling in slightly different directions from one another when they pass again into the open country. No. 3 company is swung round still further,

This diagram represents a row of soldiers marching towards a patch of rough country ; the dots indicate the successive stages in their march. While passing through the rough country their rate of march is considerably reduced. It will be observed that they are approaching the boundary line at an angle, so that the soldier on the extreme left of the page is the first to enter the rough country. His pace is slackened before that of the others, so that the line of march is altered. It is just as though the men had

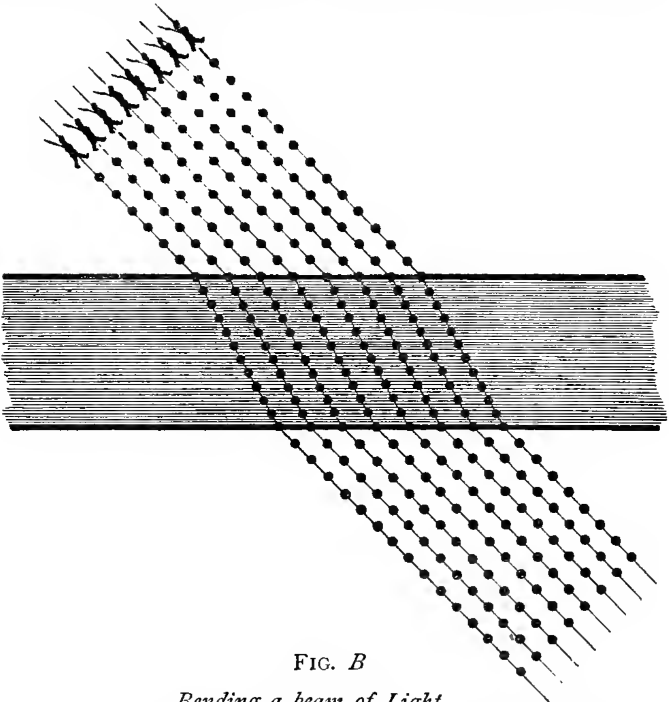


FIG. *B*

Bending a beam of Light

received the command of "Right Turn !" Then as they leave the rough country the soldier who was the first to enter is again the first to leave, so that his pace is quickened before that of the others, thus altering the line of march back to its original direction. It is just as though the men received the command, "Left Turn !"

This gives us a convenient analogy of the bending of a beam of light in passing through a piece of glass or other transparent medium, as explained in the text. Compare this diagram with the photograph facing page 172.

This diagram represents the same row of soldiers as in Fig. *B*, but here they are marching through a triangular piece of rough country. The soldier to the extreme left of page is longer in difficulties than the others, so that the man on the extreme right of page makes much better progress, and the line of march is very considerably altered. In this case it is just as though the men received the command, "Right Turn!" both when entering and leaving the rough country.

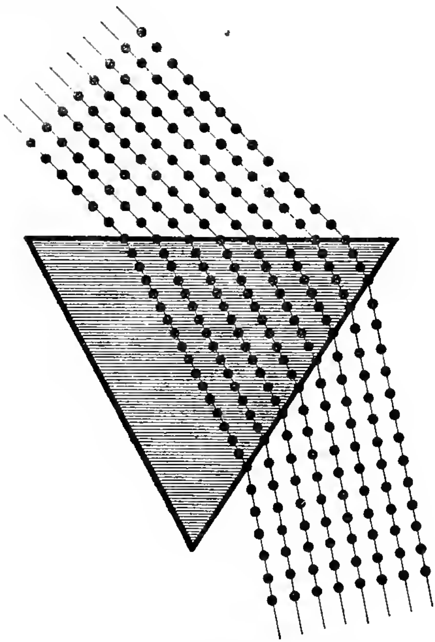


FIG. *C*

How a beam of Light is bent by a Prism

This serves as an analogy of the bending of a beam of light when passing through a glass prism. In this diagram we are considering a beam of light of any one particular wave-length, such as the waves which produce the sensation of red. The other æther waves suffer a greater refraction. The shorter the wave, the more is it bent from its original direction, so that the various wave-lengths contained in white light will be spread out when passed through a glass prism. In this way the coloured spectrum is produced, as explained more fully in the text.

and so on with the others. If a halt is called, after the companies have proceeded a little distance in the open country, the companies will be apart from each other, or spread out. In similar fashion we find the seven wave-lengths in white light spread out by passing through a glass prism, so that they form the well-known solar spectrum. The patches of colour upon the screen are really a multitude of images of the aperture through which the light is passing. If the light is passed through a circular hole, the images are circular discs of colour overlapping each other. If the aperture is a straight narrow slot, the image is composed of a myriad of straight narrow bands or lines overlapping one another.

It will be of interest to see what causes the refraction or bending of the æther waves, and why some are bent more than others. So far we have been content to know that the progress of æther waves is retarded by the glass owing to the presence of electrons, and we have pictured soldiers passing through a patch of rough country by way of analogy.

We know that the conditions of the electrons in one kind of substance vary from those in another, so we are not surprised to find that some transparent substances have a greater refractive power than others. Then we have observed already that the amount of bending depends also upon the wave-length of the æther wave itself; R waves are least refracted, and V waves suffer the greatest bending.

We have become familiar with the idea that only those electrons which can respond to the rate of vibra-

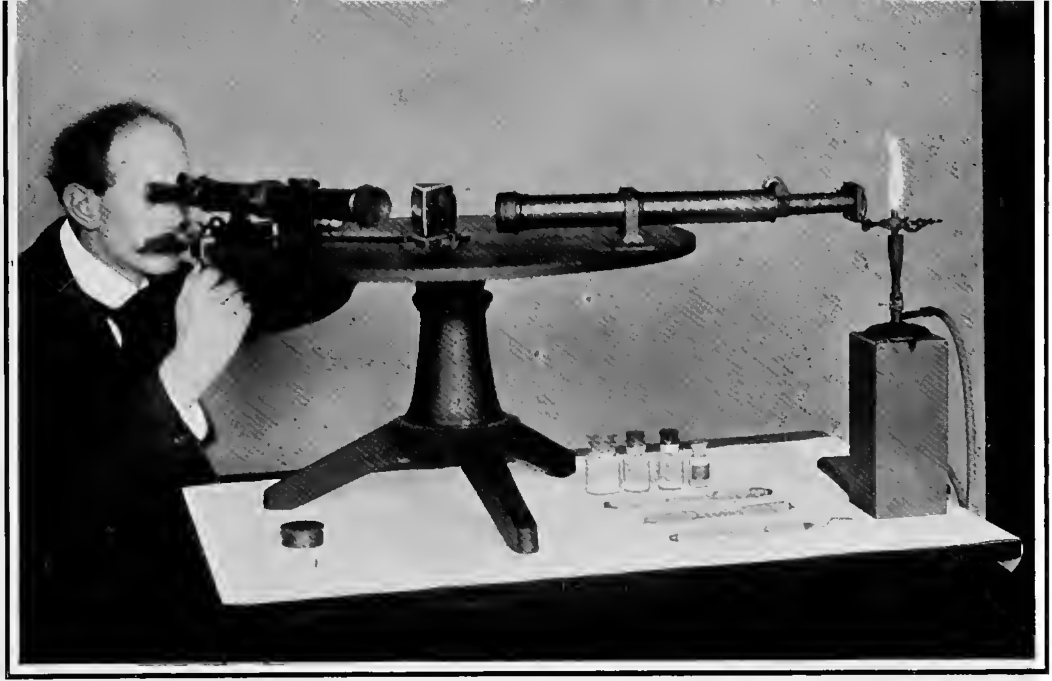
tion of the incoming wave take any very active part in opposing the æther waves. We have seen that where those sympathetic electrons exist, the æther waves can only penetrate a thin molecular layer at the surface; there they are stopped. Whether they are absorbed or reflected depends upon whether the electrons are driven away from their atoms, or whether the electrons can hold their ground and remain attached to their atoms. It is apparent that in the case of glass and other transparent substances neither of these things happen. The æther waves are not absorbed, nor do the electrons send back similar æther waves. It is most obvious that the æther waves make their way right through the glass. There can be no sympathetic or responding electrons capable of stopping the waves, but the existing electrons, although incapable of revolving at the rate of the vibrating waves, do offer some resistance or opposition, and thus retard the progress of the waves. We have seen how this affects the waves when they enter or leave the glass at an angle.

With this picture of the revolving electrons before us we can understand how some substance may be transparent to one range of wave-lengths and not to another. It will be remembered that in order to demonstrate that the long dark-heat waves could be refracted like "visible" light, we had to use a prism of rock-salt instead of glass. The glass prism is practically opaque to these long heat waves, while the rock-salt allows them to pass through just as the glass allows the waves of "visible" light to pass.

In a stained-glass window we have a good demonstration of pieces of glass treated so that they will absorb certain wave-lengths and allow other æther waves to get through. If a piece of glass allows only the R waves to pass through, we say in popular language that the glass is coloured red. Which æther waves will get through is determined by the capabilities of the electrons contained in the substance.

It is strange how much difficulty some people have in realising the simple facts of absorption and reflection. For instance, I have shown a well-educated man the solar spectrum falling upon a sheet of white paper, and asked him what would happen if we replaced the white screen with a red one. His answer has been that the red will not be seen, and that the other colours of the spectrum will be mixed with red, the blue part on the top of the red will give purple, and so on. Another man has suggested that the red will not be seen properly, but that the remainder of the spectrum will be all right. It is clear that any one giving either of these answers has not realised the meaning of reflection and absorption. The screen is "red" because its surface contains electrons capable of absorbing all the æther waves except the red-producing waves which it reflects. Therefore the whole of the æther waves spread out in the spectrum will be absorbed with the exception of the red-producing waves. We see no spectrum upon the red screen; only the small patch of red.

From what follows we shall see that we have



THE SPECTROSCOPE IN USE

When the light waves from any flame are passed through a glass prism, certain definite lines are seen in the spectrum produced, and by means of these we can detect very small quantities of matter, and distinguish one elementary substance from another. It is by this means we have learned the constituents of the heavenly bodies.

obtained many interesting ideas from the spectrum. In order to make observations conveniently, the glass prism is mounted between two tubes, as is shown in the accompanying illustration facing p. 218. One tube is provided at one end with a vertical slot, through which the light that is to be examined is passed. This slot is usually adjustable, so that its width may be altered at will. At the other end of this tube is a lens, so that the beam of light from the slot emerges through this lens as a pencil of parallel rays. This tube with the slot and lens is called a *collimator*, but it should really have been called a collineator (Latin *col*, together, and *linea*, a line). It is a curious thing that the verb *collimate* ever got into our English language. It was only by mistake that it did so; it was derived from a fancied Latin verb *collimare*, which was really a false reading of *collineare*. I mention this in passing, as the name of the tube—*collimator*—looks rather puzzling. The construction of the tube is simplicity itself; a slot at one end, and a lens at the other. When the pencil of light emerges from this tube it falls upon the glass prism, striking it at an angle. In passing through the prism the light is dispersed into its spectrum, and is bent round so that it enters the second tube, which is simply a short telescope for magnifying the image of the spectrum. The complete apparatus is called a *spectroscope*. Suitable means of measuring the amount of bending of the rays may be added, in which case the instrument is sometimes called a spectrometer.

It may be remarked in passing that the glass prism is replaced sometimes by a *grating*. The dictionary meaning of this word is a partition of parallel cross-bars, and we are all familiar with street gratings and the like. The *grating* referred to here is a series of very fine parallel lines ruled on a glass plate. When ordinary white light passes through this it is spread out into its spectrum. There is one difference between the action of a grating and that of a prism. The latter spreads out the beam of light so that it forms a single spectrum, whereas the grating forms a number of spectra. A little white light gets straight through between the lines, and forms a bright white image at the centre of the screen. On either side of this there are formed several spectra of diminishing brightness. If the fine lines are ruled on a piece of polished speculum metal, the light will be reflected in the form of a spectrum. A grating of this kind has some advantages over a prism, but we need not trouble with further detail here.

If one looks at a very fine speculum grating one does not see the lines, but the whole surface appears to be rainbow-coloured. This property of sorting out the different wave-lengths of light is not the sole right of glass prisms and gratings. In these days of petrol motor-cars, even the least observant of pedestrians must see at times the most exquisite colours reflected from the damp surface of the roadway upon which some petrol has fallen. There we see a medley of colours, and it is obvious that many of the different

wave-lengths have been separated from the white light falling upon the oily surface. In this case the sorting out is caused by the interference of reflected æther waves, and the irregularity of the sorting out is due to variations in the thickness of the film of oil lying upon the damp surface. The same phenomenon is seen upon large soap-bubbles, and this principle of interference has been used by Professor Lippmann to produce natural-colour photography. His process, however, is practically a laboratory experiment.

The colour effect produced by the surface of mother-of-pearl is due to very fine lines similar to the speculum grating. It is a remarkable fact that if a sealing-wax impression is taken of the surface of mother-of-pearl, those very fine lines are sufficiently impressed upon the wax to produce a similar colour result.

Let us go, in imagination, into a dark room and see what we can learn by the aid of a spectroscope. We have arranged a convenient method of heating a piece of iron—say, by means of an electric current—and we place the spectroscope in such a position that it will receive any æther waves set up by the heated iron. For some time we see nothing, either when we look through the instrument or look directly at the place we know the iron to occupy.

As soon as the iron begins to glow we look through the instrument, and we see that section of the spectrum which produces the sensation of red; we see the red patch and nothing more. We know from this that there are electrons within the iron revolving at a speed

of four hundred billion revolutions per second. As the temperature rises we observe that the piece of iron glows more brightly. Looking through the spectroscope we see the orange part of the spectrum appear, then comes the yellow, and gradually the green, blue, indigo, and violet are added in turn. We have witnessed the complete spectrum being gradually built up as electrons were thrown into the different rates of revolution. We are not to think that there are, within the iron, electrons which would naturally revolve at these various speeds if their atoms were free from collision with one another. The reason why we have such a variety of æther waves emitted by the heated iron is that the electrons are being forced to these paces by the commotion among the atoms, due to their rapid vibration, and as the atoms are crowded together the electrons are hampered, so we find all sorts of rates of revolution. Every solid body when raised to a white heat will behave in the same way; it will produce a complete spectrum. A complete spectrum, such as this, tells us nothing of the nature of the substance which is emitting the light. We must have the atoms freed from one another to such an extent that their electrons may revolve at their natural periods.

If we melt the iron we free the atoms from their solid grip, but if we examine the light from the molten metal we still see a complete spectrum. If we have any means of raising the temperature to 6000 degrees Fahrenheit (3300 degrees Centigrade), we shall cause

some of the atoms of the iron to escape into the air in a gaseous condition, just as we have water vapour rising from boiling water. If we direct the spectroscope towards the vapour, and cause white light from some hotter source to pass through the iron vapour, and then examine the resulting light, we see a very curious phenomenon. We see the spectrum of white light, but it has a series of fine dark lines crossing it at intervals. It is apparent that we have lost some of the æther waves which were contained in the white light. We have not got the continuous spectrum which the white light should produce; there are blanks here and there. We think of the spectrum as being composed of a myriad of images of the slot, all blended together to produce one broad band, just like the coloured warp threads of a rainbow ribbon. In the present case a number of threads are absent here and there.

Looking through the spectroscope at the light which has passed through the iron vapour, we have no difficulty in suggesting where the missing æther waves have gone. There is only one possible conclusion: they have been absorbed by the iron vapour, or in other words, they have been stopped by the electrons attached to the iron atoms. The waves which succeeded in getting through to the spectroscope have found no responsive electrons in the vapour.

Suppose we take a photograph of this discontinuous spectrum. Of course we must take the photograph through the spectroscope, and as the photograph will

show no colours, we take care to mark off the positions of the different coloured sections. We see so many lines occur in the red section, so many in the green, and so on. We find a great number of lines throughout the spectrum.

We take other photographs of light passing through the vapours from different elementary substances, and when we compare them with each other we see that they are quite different. We always get the same lines from the one elementary substance. In the light photographed through sodium vapour we find only two black lines, and these occur in the yellow part of the spectrum. These lines are so close together that in a simple spectroscope they appear as a single line. Why should lines appear? The lines are simply images of the slot through which the light is passing into the spectroscope.

From the foregoing we see that an element must be in a gaseous state before we can produce its line spectrum. We have seen that sodium vapour absorbs two definite wave-lengths situated in the yellow part of the spectrum. We know that the vapour must contain electrons capable of revolving at speeds corresponding to these particular waves. It therefore stands to reason that if these electrons can be thrown into their natural periodic revolutions they should emit waves corresponding to these same rates of vibration. That is exactly what we do find. If we burn a piece of sodium in a bunsen flame and examine the flame of the burning sodium, we find two bright yellow

lines in exactly the same positions as the two dark lines have already appeared in.

If we burn hydrogen gas, and examine the flame by means of the spectroscope, we find three bright lines. One of these is a very distinct line in the red section, and another in the blue part, while the third line is somewhat fainter, and is situated further along in the blue towards the violet end of the spectrum. Other fainter lines may be detected with more delicate apparatus. With a small pocket spectroscope one may distinguish these three lines very well.

We have another very convenient method of examining the spectra of gases. If we fill a glass tube with hydrogen gas and then connect the tube to an air-pump, we can withdraw most of the gas, leaving what we call a vacuum. Although we speak of these as vacuum tubes, we know that they must contain a very small quantity of air or gas. A tube may be exhausted till there remains less than one-millionth part of the air that would fill the tube at ordinary atmospheric pressure. In the present case the exhaustion is not carried to such a high degree. We only wish to separate the atoms sufficiently to give their electrons freedom to revolve around the atoms at their natural or periodic rate. Our next requirement is to make this collection of free atoms self-luminous. We know that we can make the contents of a vacuum tube luminous by passing an electrical discharge through the tube. When we connect the electrodes of the tube to an induction coil or to an electrical machine,

we have quite the effect of an aurora within the tube. The colour of the glow will vary according to the kind of gas used in the tube. In the present case we shall have a very pale-red light from the hydrogen gas. We may examine this light through the spectroscope, and we see the well-known hydrogen lines. Again the lines are bright—just as though the gas were being burnt; it is only when light passing through a vapour is examined that we see dark lines, indicating that these wave-lengths have been absorbed by the gas.

The foregoing method of examining the spectra of gaseous elements has been of very great advantage. It has given us a means of obtaining the spectra of rare gases, which we cannot obtain in large quantities. It enables us also to produce the spectrum of oxygen, and of other gases, which are non-inflammable.

As each elementary substance has its own definite series of lines in the spectrum, we can tell from any given spectrum what substances are producing it, no matter how complicated it may appear. For instance, if we photograph the spectrum of the Sun, we find many thousands of lines scattered throughout the spectrum. By carefully marking off those lines produced by hydrogen, those produced by iron, and so on, we are able to tell exactly the different elements contained in the Sun. We find no fewer than forty different elements, and among these are hydrogen, sodium, iron, copper, nickel, and zinc. These all exist in gaseous form in the photosphere or outer

atmosphere of the Sun. These vapours absorb certain wave-lengths of the continuous spectrum produced by the glowing Sun, and thus produce definite dark lines in the spectrum.

We can learn a great deal about objects around us by handling them and examining them; we cannot tell always what they are made of. Think of the Sun more than ninety million miles beyond our reach, and yet we can tell what it is made of. The chemistry of the stars is due entirely to the spectroscope.

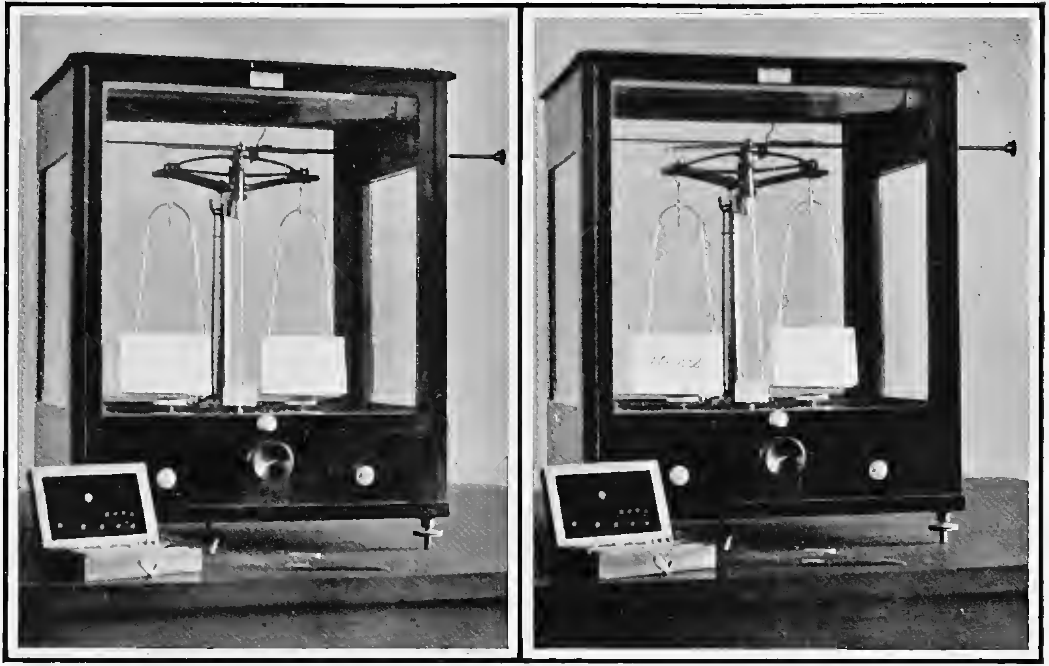
It is a curious fact that Sir Isaac Newton never observed these dark lines in the solar spectrum. They are present even in the spectrum formed by a common glass prism, such as those used on old-fashioned gasaliers. It has been suggested that Newton employed an assistant to examine the spectrum for him. It might be asked how the assistant did not observe the lines. I could quite imagine him passing over these little black lines as due to some irregularities in the glass prism. Of course, he could have tested this by simply sliding the glass prism to one side or the other and watching whether these lines moved with the prism or remained in their definite places in the spectrum. We must remember that two hundred and fifty years ago men were not trained to those exact methods of deductive experimenting to which we have become accustomed in these later days.

One very interesting point in connection with the spectroscope is the exceedingly small quantity of a substance which it can detect. If we burn a few

grains of common salt in a bunsen-burner and examine the light emitted, we see the sodium lines very distinctly even when using a pocket spectroscope.

It is a well-known fact that a single drop of blood in a tea-cupful of water will show its characteristic spectrum when white light passing through it is examined. In this way it is possible to distinguish between blood drawn from an artery and from a vein, even although the quantity is so small. Arterial blood is, of course, oxidised as it flows from the heart, the blood having previously received oxygen from the lungs. The blood returning by the veins is deoxidised, having given up its oxygen to the body. In the spectroscope there will be seen dark absorption lines representing oxygen if the blood is arterial, while these will be wanting if the blood is venous. We might weave a *Sherlock Holmes* story around this fact. Some beautiful lady is found dead under mysterious circumstances. Neither the doctors nor the police can offer any explanation. A "Sherlock Holmes" is called in and draws a single drop of blood from one of the arteries. A spectroscopic examination of this tells him that the lady has undoubtedly died of suffocation from the fumes of burning charcoal, for in such cases the whole of the blood in the body becomes deoxidised.

From the foregoing it is apparent that a very small quantity of matter can be detected by the spectroscope, but these are by no means extreme cases. To state that a good spectroscope can detect one-millionth part of a milligram will not convey much meaning to those



DETECTING A SMALL QUANTITY OF MATTER

In the left-hand photograph two pieces or paper have been cut so that they exactly balance each other upon the pans of a very sensitive balance. A single word "atoms" has been written with a lead pencil upon one of the papers, and the additional weight may be observed in the second photograph. Such balances may detect a very small quantity of matter, but the spectroscope will detect less than one-millionth of the matter contained in the word pencilled above.

unaccustomed to work with milligrams. With the aid of the illustration facing page 228, we may grasp some idea of the great sensitiveness of the spectroscope. Here we see a very sensitive chemical balance, which can easily detect the weight of a word written in pencil. In the first illustration we see two pieces of paper which exactly balance one another. We then take one paper and write a single word upon it with a lead pencil. In doing so we have rubbed a very small portion off the point of the pencil on to the surface of the paper. We see no difference in the point of the pencil; it is still good to write many hundreds of words. But our balance is quite able to detect the increased load, as is seen from the second photograph. In this case we have detected about four milligrams of matter, and this very sensitive chemical balance can do even finer work. Here we see the presence of a very small quantity of matter detected by the balance. The spectroscope, however, can detect one four-millionth part of this quantity of matter. Think of the minute quantity of lead rubbed off the pencil, and try to imagine this divided in four million parts; the spectroscope could detect one of these infinitely small parts.

Our interest in the spectroscope does not end here; we shall see from the following chapter how this single piece of apparatus has added to our knowledge valuable facts concerning the far-distant stars.

CHAPTER XV

THE BIRTH OF A STAR

How we take a star's temperature—An element may have more than one spectrum—Wireless telegraph analogy—The temperature of the Sun—The birth of a star—Building up the atoms—The atoms breaking down—Reservoir of latent energy—How we know that some distant stars are approaching us at great speeds—Railway whistle analogy—How the stars send us wireless messages—Experimental proof that light is due to electrons revolving around atoms—A marvellous experiment.

HOW can we possibly tell the temperature of a star distant many billions of miles from us? Even had we never heard before that such a thing was possible, I think we might make a very good guess at how such a thing could be done. We could at least suggest a possible means of comparing the temperature of one star with that of another, if we realised what took place when we gradually heated a piece of iron and examined the light emitted by it. Looking through the spectroscope we saw, first of all, only the red part of the spectrum. Then as the temperature of the iron was increased, step by step there appeared the orange, yellow, green, blue, indigo, and violet parts. We shall know then that if a star produces only the red end of the spectrum, that star is not so hot as one which produces the red and the orange. The more of the

spectrum that appears, the hotter will be the star that is producing it. This convenient thermometer does not end with the violet part of the spectrum; other æther waves of higher frequency are produced. These æther waves of ultra-violet light will affect a photographic plate, so by means of photography we can extend the scale of our thermometer far beyond the limit of the visible spectrum. When we find two stars producing the same length of spectrum, we know that these two stars are at similar temperatures.

Each element has its own distinctive line spectrum, but we need not suppose that it is impossible for a definite spectrum to show some variation. For a long time it was believed to be quite impossible that the line spectrum of an element should vary in any way whatever. But nearly half a century ago two eminent Austrian scientists published a paper stating that some of the elements could be made to produce totally different spectra. Sir Norman Lockyer, who has done so very much for this branch of science, demonstrated in a very clear manner that the spectra of some elements showed extraordinary variations when the element was at different temperatures. The spectrum produced by sodium when burned in a bunsen flame is very much simpler than that produced by the same element when placed in an electric arc, while a further change is obtained by using an electric spark as the source of illumination. Under these three conditions sodium produces different wave-lengths in the surrounding æther. The flame spectrum of iron shows

only a few lines, while its arc spectrum shows about two thousand lines. It must be clearly understood that the spectrum of an element is always constant under the same conditions. A certain arrangement of lines is known to us as being produced by sodium at the temperature of a flame, while we recognise another arrangement to be due to the same element at the much higher temperature of the electric arc. We see that the reading of stellar spectra is by no means a simple thing. A certain arrangement of lines not only indicates the element, but gives us some idea of the temperature at which the element is. Here, therefore, we have a further reading of our stellar thermometer. There are other indications of temperature, but enough has been said to show how our ideas of the temperatures of distant stars has been acquired.

Scientists have been able to read a great deal of valuable information from the spectral lines of the Sun and stars. It is just as though the æther waves were wireless telegraph messages despatched by the revolving electrons in the far-distant stars, our spectroscopes being the telegraph receiving instruments. With the aid of photography we get those stellar telegraph messages to record themselves, and the different arrangements of spectral lines form the telegraphic code. With this analogy in view we may look upon Sir Norman Lockyer, and Sir William and Lady Huggins, as the chief telegraphists.

Lockyer has shown that the spectral lines of iron

in the photosphere or luminous envelope of the Sun are the same as those produced by iron at the temperature of the electric arc. This telegraph message informs us that the temperature of the photosphere of the Sun is about six thousand degrees by the Centigrade scale. This telegraph message has corrected a very erroneous idea which man had formed previously; fifty years ago we believed the temperature to be several million degrees.

Without going into the details of the spectra, it will be of interest to see what other telegraph messages we have received upon this planet from the heavenly bodies. We are not going to trouble about the code signals, but we shall see what the telegraphists have made out of the messages received.

We learn that the great Sun is cooling down very gradually, and that many other stars are doing the same. But we also learn that some stars are actually getting hotter, and we estimate the hottest stars to be about thirty thousand degrees Centigrade.

Our chief telegraphists have read the following message for us, and whether or not they may have made a perfectly correct interpretation of the code signals, the message is of great interest, as it suggests a very reasonable explanation of the birth of a star.

First of all we have a great *nebula*, occupying a space measured in millions of miles. This nebula is composed of swarms of *meteorites*, which are fragments of solid matter containing the elements as we know

them on this planet. These meteorites are cold bodies, and we shall see in a later chapter whence they have come. However, we can imagine these meteorites colliding together as they tend to gravitate to the centre of the mass. These collisions will produce heat, so that the temperature of the mass will rise gradually as it condenses. In the course of time the temperature rises to such an extent that the whole mass, now greatly reduced in bulk, becomes gaseous; this is the condition of the hottest stars. When this condition has been reached there are no solid particles remaining to cause further collisions and keep up the temperature; the star therefore commences to cool.

While the star is in its hottest condition we receive wireless messages in the spectroscope, which are translated to mean that some of the elements have been dissociated into simpler forms, owing to the enormous heat, probably some twenty to thirty thousand degrees Centigrade. To distinguish these dissociated elements, they have had the prefix *proto* given to them as a title. We speak of proto-hydrogen, proto-magnesium, and other proto-elements as existing in very hot stars. While in others not quite so hot we find proto-iron, proto-copper, and so on. As the temperature decreases these proto-elements disappear and the regular spectral lines of the elements appear, just as we have them on this planet. The colder the star the more elements do we find in it. There can be no doubt that these have been gradually built up, or condensed, in the process of cooling; it is undoubtedly a case of evolu-

tion. Comparing the messages from stars of different temperatures, we find that only the lightest elements exist in the hotter stars, and that the heavier elements appear practically in order as the stars cool.

We have, no doubt, become familiar with the idea that the atoms of all the elements are composed of electrons. From the foregoing paragraph we see that, at the very high temperatures which exist in some stars, only a few electrons can club together to form an atom, whereas at lower temperatures an increased number of electrons congregate and form a heavier atom.

It is natural to ask, at this point, what happens when a star becomes so cold that it ceases to glow. Let us say, when it has got into the condition of this planet of which we have the good fortune to be tenants. Here we have some eighty different elements, the heaviest of all being *uranium*. What can happen next? Will this planet, and ultimately the whole Universe radiate away its heat and then collapse into one cold dead mass? Until recently there did seem no other reasonable conclusion. It will be remembered, however, that in an earlier chapter we considered the phrase "as dead as a door-nail." We know nowadays that there is a tremendous internal activity in every piece of so-called dead matter. Is it not possible, then, that the atoms of matter may break up again into other forms and ultimately free those rapidly revolving electrons of which they are composed? There is no need for speculation upon this possibility;

we have actual proof that this is taking place in uranium and other heavy elements. The subject is of so great interest that we shall deal with the breaking-up of the atom in a separate chapter by itself.

Reading between the lines of the wireless messages reaching this planet from the outer world, we picture the Universe not as a machine wound up by the Creator and allowed to run down to a state of rest, but as an eternal change from electrons to proto-elements to elements and back to electrons.

While the foregoing is intended to indicate the scientific ideas of to-day concerning the Universe, it must be kept in mind that there is a certain amount of reading between the lines, or, in other words, of speculative thought. When we read between the lines of a friendly letter, we sometimes read correctly, and unfortunately we sometimes read wrongly. It remains for future generations of men to see how much of our reading between the lines has been in the right direction.

There is not the least doubt that many of the theories we hold to-day must give place to newer ideas. More modern theories will be added from time to time. We should recognise the fact that our present ideas are merely tentative, the best we can suggest so far as we have been able to read the secrets of nature.

Before leaving the subject of the spectroscope, there is another kind of wireless message received from the distant stars which it will be of interest to notice.

Sometimes when examining the spectra of stars a very slight alteration of the lines is observed. The nature of the alteration is that the spectral lines are not in their normal positions in the spectrum. In some cases the lines have moved slightly up the scale towards the ultra-violet end, while in other cases the lines are found slightly further down the scale than the lines of the same element usually occupy. It is evident that the rates of vibration in the first case have been increased, and in the second case decreased. The only reasonable translation of these messages is that the star being examined in the first case is moving towards the observer, and in the second case it is receding. We have a very apt analogy for this in every-day life. It is an analogy well known in Physics, and is as follows—

At some time or other most of us have observed how the pitch of a locomotive's whistle changes as an express train approaches us and recedes from us. Indeed, we might think that the locomotive was using two whistles, if we did not know that its whistle was sounding only one definite note. The cause of this increase and decrease of pitch in the whistle is not far to seek. The whistle is setting up one definite rate of air vibration all the time; but as the train rushes towards us these arrive, one after the other, quicker than they would if the engine were standing in one position. Hence we hear a slightly higher note. Imagine the whistle giving a definite number of blows to the atmosphere in each second

of time. We then picture the first sound wave set up by the whistle to be travelling towards us; but the engine darts forward as it gives the second blow. It is just as though the engine made up very slightly upon the first sound wave before it dealt the second blow, so that the air waves follow each other closer than they would otherwise do. They arrive in quicker succession than they would do if the engine remained standing while it dealt out the blows. More vibrations arriving per second means a higher pitch. On the other hand, when the engine is rushing away from us, the vibrations or sound waves will be a little farther apart from one another, the engine receding at each blow. Fewer vibrations arriving per second means a lower pitch.

With the aid of this analogy we can read the meaning of the slightly altered spectrum. If we find that the spectral lines have moved up the scale towards the violet end of the spectrum, then we have no hesitation in saying that the increase of "pitch" is due to the star, which is emitting the æther waves, rushing towards us. On the other hand, if the lines are found nearer to the red end of the spectrum than the normal position for such lines, then we know that the star is receding from us. By very exact measurements of the amount of displacement of the spectral lines the rate of motion can be calculated. In this way we know that Sirius (the Dog Star) is approaching us with a velocity of over nine miles per second. Fortunately it has a very long race to run; our

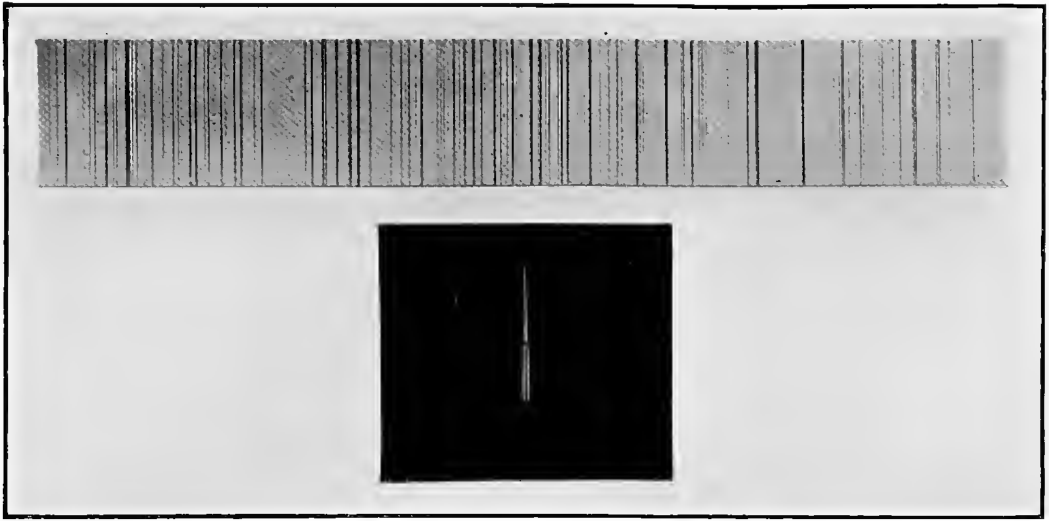
planet will not be here to see the finish. Some other stars have very much higher velocity in the line of sight. In the same way the spectroscope informs us that Capella is receding from us with a velocity of fifteen miles per second, while others are running away at double that speed. There is no rough estimate, or guess-work, about these velocities; with modern instruments and methods it is possible to determine the actual velocity with an accuracy of less than half a mile per second, even for the most distant stars.

We have no doubt whatever that all these wireless messages, received in the spectroscope from any possible source, have been sent off by revolving electrons. Indeed, we can easily demonstrate this fact in the laboratory. As long as this idea of the cause of æther waves was merely a theory built upon mathematical calculations, the general body of people paid little attention to it. About 1881 Professor H. A. Lorentz, of Amsterdam, suggested the theory that the æther waves of light were produced by means of minute charged corpuscles revolving around atoms. This was a reasonable theory, but no experimental proof could be brought forward at that time to support it. However, in 1897, Professor Zeeman, of Leyden, demonstrated by experiment in the laboratory that these revolving particles did exist, and that they did undoubtedly produce the æther waves of light. Zeeman's experimental proof, which is of the highest importance, is as follows.

We have become familiar with the idea that any alteration in the speeds of the revolving electrons would alter the wave-lengths of the æther waves produced by them. But how can we hope to act directly upon those electrons to cause any alteration of speed? We know that electrons in steady motion constitute an electric current, and we also know that electric currents are susceptible to the influence of a magnetic field. It was reasoning of this kind which led physicists to try what effect a powerful magnetic field might have upon a body emitting æther waves of light. It was believed at first that any effect would be too small to be perceivable, but once more the spectroscope came to the rescue. We have seen how the spectroscope can detect very small variations of wave-lengths in the æther.

Professor Zeeman placed a sodium flame between the poles of a very powerful magnet, and arranged his spectroscope so that he could examine the light emitted by the flame. When the instrument was adjusted he saw the well-known sodium lines. Then switching on the current to the electro-magnet, each line was seen to split up into two parallel lines (see illustration facing this). Whenever the magnetic field was withdrawn from the flame the spectral lines appeared single as at first. What caused this curious phenomenon?

It is clear that some of the æther waves were reduced in speed, and therefore took up a slightly lower position in the spectrum, while other waves were increased in speed and produced a spectral line slightly further up



(1) DARK LINES IN THE SOLAR SPECTRUM

(2) ZEEMAN EFFECT

The upper illustration is part of a photograph of the solar spectrum. The meaning of the dark lines which appear in the photograph is explained at page 226.

The lower photograph is a double one. First of all a single spectral line of sodium was photographed. Then a powerful magnetic field was applied to the sodium flame, and the second photograph was taken showing the same line split into two lines. See page 241.

This photograph was taken in the late Lord Blythswood's laboratory.

the scale, thus producing two distinct lines in place of a single one. This meant that the speed of some electrons had been decreased and that of others increased. This is exactly what we should expect. In the great congregation of atoms in the sodium flame there must be electrons with their orbits lying in all planes, so that if one could see them one would observe electrons revolving in all directions. Those going in one direction will be accelerated by the magnetic field, and those going in the opposite direction will be retarded; hence the change of the spectral lines.

There are many other points of interest in connection with the Zeeman effect, but enough has been said to serve our present purpose. We see that there is direct experimental proof that light is due to revolving electrons. This is one of the most interesting experiments I have ever had the pleasure of seeing. It is not an elaborate experiment, but it requires the best modern apparatus. More than one experimenter had looked for this effect in vain, and Zeeman himself had made an unsuccessful attempt. However, in 1897, with more perfect apparatus Zeeman was successful. It is interesting to watch the spectral lines of the sodium flame while a friend switches on the current to the large electro-magnet. One sees the lines become twofold immediately, and their return to single lines indicates the withdrawal of the magnetic field.

It is a marvellous experiment. Here we are controlling directly those infinitely small electrons which are circling around the invisible sodium atoms. We

are operating upon things which are far below the range of the most powerful microscope, and yet we can read what is taking place, by recording the waves produced in the æther and analysed by the spectroscope.

CHAPTER XVI

THE AGE OF THE EARTH

No idea of a law of uniformity among the heavenly bodies—An insect analogy—Youthful ideas of the world's age—Man the same for thousands of years—The geologist's book of ancient history—Lord Kelvin's estimate of the Earth's age—Does radium play a part in maintaining the Earth's temperature?—The birth of the moon—The forming of the oceans—Calculating the age of the oceans—The birth of the solar system—Are the electrons eternal?—Interesting statement by Lord Kelvin

THOSE wireless messages, received by the spectroscope from the outer Universe, which we have been considering in the preceding chapter, do not bring us any direct information regarding the age of the Universe. Indeed it would be unwise to judge the comparative ages of the stars by their temperatures, just as it would be erroneous to judge the ages of men by their relative heights. As man passes from infancy to manhood he grows taller, but a youth measuring five feet is not necessarily older than another measuring only four feet. However, when one is asked to guess a child's age, or more particularly if one is asked to say which of two children is the older, one usually depends very largely upon the factor of height. And although we abandon all idea of a law of uniformity, we are satisfied with a

general comparison of the stars by their relative temperatures.

But all the stars are just as they have been since man first made definite observations of them. No one has ever seen a star change from one condition to another. Imagine some insect, whose whole life was summed up in a single day, being endowed with a reasoning intelligence. As it looked on mankind it would see living creatures of different sizes, and it might reason that the smaller creatures gradually grew to be larger creatures; it could see a minimum and a maximum, but it could witness no actual change taking place during its short day, and so it could form no opinion as to the rate at which men grew. It is quite evident that we cannot form any idea of the age of the Universe by direct observation.

Man, however, is the tenant of a planet which he believes to have passed through all the different conditions which he sees among the stars. Therefore his most natural plan is to examine the interior of his own planet, and try to read its history by means of geology.

Possibly some of us have recollections of our own early ideas of the age of the Earth. I can remember, when I was a boy, looking at the date on the first page of Genesis—4004 B.C.—and calculating that the Earth was therefore about six thousand years old. Of course, our youthful idea of the Creation was that it occupied seven days of twenty-four hours each, including the day of rest. I can remember distinctly how I tried to

realise what those six thousand years meant, and it is evident, from the analogy adopted, that the thinking was done in church. I pictured twenty very old women occupying a pew in front. Each woman was exactly one hundred years of age. It was clear that if those twenty imaginary women had appeared upon this planet in succession, the second one appearing as the first one died, and so on, they would make a complete connecting link between the time of Christ and the present day. In other words, the first old woman would have lived about two thousand years ago, and I had only to imagine three similar pews of old women to take me back to the time of the Creation. It all seemed quite reasonable and real at that time, and made the imagined age of the Earth quite realisable.

The boy of to-day can only have such thoughts as the foregoing at a very early age, but I was amused with an incident which happened recently. I was walking through a cemetery with a little fellow of seven years, when he suddenly pulled me up in front of an old-looking tombstone upon which the family name of *Adam* was conspicuous. With anxious curiosity the little fellow asked—"That isn't the grave of old Adam of the Bible, is it?" The boy-mind of to-day, however, soon begins to inquire as to how old the world really is.

Man cannot hope to dig very deep into the interior of the Earth, but there are great mountain clefts, in different parts of the world, and in these the different strata of deposits may be seen. In this way man has

been able to look back over the pages of the Earth's past history.

From excavations made in Egypt we see that at least four thousand years ago there lived men and women very similar to ourselves. From an amusing little incident which was brought to light in one of the more recent excavations one sees how very like the youth of thousands of years ago must have been to the youth of the present day. I heard one of the excavating party tell that they found upon a wall an informal inscription, or scribble, which translated into English reads—"Julia, my Julia, is a little pig." It must be presumed that the word pig was a term of endearment in those days. I recollect another trivial incident related by the same authority. It was the inscription upon a tombstone erected by a husband to the memory of his deceased wife. The translation of this pathetic inscription was—"She had no fault but that she left me."

We see therefore that during four thousand years man has really changed very little. Indeed it is clear that the time required for the evolution of man from the simplest living organisms cannot be reckoned conveniently even in thousands of years. We are not very surprised on this account to learn that the late Lord Kelvin reckoned the age of the Earth as a habitable planet to be about twenty million years. His calculations are based upon the physical condition of the Earth; its internal temperature. From this he calculates that it has taken twenty million years for

the Earth to cool down from a molten globe to its present temperature.

Since the discovery of Radium, which continually emits heat, suggestions have been made as to the possibility of such radio-active substances assisting in maintaining the Earth's heat for a longer period than would otherwise be the case. A similar suggestion has been made with reference to the life of the Sun. It is evident that the late Lord Kelvin did not count these suggestions as carrying any weight with them. In a letter written by him in 1906, and published at a later date in the *British Weekly*, Lord Kelvin made what is believed to be his latest statement upon this subject. Speaking of the Earth and the Sun, he says—"It seems almost infinitely improbable that radium adds practically to their energy for the emission of heat and light." It should be noted, however, that some very eminent scientists of to-day think the suggestion quite a reasonable one.

The amateur may judge the age of a full-grown horse by its appearance or by its activity, but the expert can tell its age from its teeth, up to a certain age. We may count the age of a tree from its possession of rings, and the age of some fishes may be reckoned from certain markings on their scales. There are several methods of calculating the age of the Earth, but before considering these it may be helpful to have a general statement of the scientific ideas of to-day concerning the evolution of this planet from a molten globe to its present condition. In the

days of long ago, when this planet was a molten mass, it revolved upon its axis at an enormous speed, and was surrounded by a dense atmosphere of water vapour. We picture the tidal action of the Sun producing enormous tidal waves in the outer envelope of this molten globe. One such enormous wave rose to so great a height that it broke away from the main body, and in this we see the birth of our moon. According to Sir George Darwin, this great event happened some fifty-six million years ago.

As the planet cooled, the water vapour became liquid, and oceans were formed in the hollows of the Earth's surface, which had become irregular under the enormous pressure of the water atmosphere, which probably amounted to about five thousand pounds to the square inch. The boiling waters of the oceans would cool, and sedimentary deposits would be formed. It is the presence of these deposits in the Earth's crust which constitute the geologist's book of ancient history.

Geologists were so impressed at first with the enormous time required for the formation of these accumulated deposits that they declared that the age of the Earth could only be counted in "eternities." Some geologists of to-day will not be content with less than thousands of millions of years for the Earth to become solid and reach its present condition.

It is interesting to note one method of determining the time which has elapsed since the oceans were formed upon the Earth. The oceans, having been

formed from the gaseous water atmosphere, were originally fresh water, and only became salt very gradually by the rivers carrying down sodium. Professor Joly, of Dublin, has calculated the amount of sodium contained in sea-water, and also the amount carried down by all the rivers in one year. The latter figures out to be about one hundred and sixty million tons of sodium per annum, while the amount of sodium contained in all the oceans is at least ninety million times as much. Professor Joly therefore assumes that it has taken ninety million years for the oceans to reach their present degree of saltness.

It will be observed that Professor Joly's estimate is in excess of Lord Kelvin's minimum of twenty million years, but at one time Lord Kelvin's estimate ran as high as four hundred million years; he ultimately favoured the lower figure. Sir George Darwin's calculation of the age of the moon comes between Lord Kelvin's minimum and Professor Joly's estimate. So we see that the scientific men of to-day are by no means agreed as to the time which has elapsed since this planet of ours became a solid body, but all are agreed that the time can only be measured conveniently in millions of years. If we admit that many millions of years have been necessary for the cooling down of this planet from a temperature of five thousand degrees, what shall we say then of the time required for it to cool down from thirty thousand degrees when it was one of the hottest stars?

One thing is clear, this planet had a beginning and

it must have an ending also. We think of the Earth as having a definite life from the time when it and the other members of the solar system broke away from the great nebula which originally occupied the space of the solar system. We can realise that all the heavenly bodies had a beginning and will have an ending, and that the very atoms of matter had also a beginning and must have an ending, but what about the electrons of which the atoms are composed? Are they eternal and never-changing? May not the electrons themselves have structures as intricate as the atoms? Here Mendeléeff's theory of æther particles might come in; the electrons being pictured as systems of revolving æther particles. It is no wonder that man's brain reels before the infinitely great things of the known Universe on the one hand, and the infinitely small things of Nature on the other hand.

We do not doubt the evolution of man, although we may desire to modify Darwin's theory. Surely we must accept also the theory of the evolution of matter? The old gulf between living bodies and not-living matter is not so wide as it once was; the real difference may be somewhat analogous to that of an electrified and an unelectrified body. But we believe that life is something distinct from matter and energy; in the living body there is something which is not present in the dead body.

To admit evolution does not mean that things are as we find them because of some blind unliving

force. In this connection Lord Kelvin made some very interesting statements in a public address a few years ago. He said, "It is impossible to conceive either the beginning or the continuance of life without an overruling creative power. . . . I feel profoundly convinced that the argument of design has been greatly too much lost sight of in recent zoological speculations. Overpoweringly strong proofs of intelligent and benevolent design lie around us, . . . showing to us through Nature the influence of a free will, and teaching us that all living things depend on one everlasting Creator and Ruler."

CHAPTER XVII

WHENCE CAME LIFE?

The cycle of life—A curious rumour—Life dormant for thirty years—Lord Kelvin on the origin of life upon this planet—A mistaken idea—Pasteur's great discovery—Life originated in the sea—The construction of all living things—What protoplasm is—Will life ever be originated in the laboratory?

A VOLUME under the present title would not be complete without some reference to the scientific ideas of to-day concerning the origin of life.

I can imagine some of the old school being displeased that such a question—"Whence came life?"—should be raised at all; it should be sufficient that the Creator made man and all other living creatures. However, as we have seen in the preceding chapter that we believe in an evolution from electrons to atoms, from one kind of atom to another, from simple atoms to compound molecules, and ultimately in some mysterious way to living matter, it is natural to inquire into the origin of life. The true man of science does not desire to drive the Creator from his Universe; he desires only to see the manner in which the Creator has caused Nature to work out his designs.

If any scientific man were to maintain to-day that the Sun was the originator of life, he would be put

down as a quack, and rightly so. It is clear to all that the Sun is absolutely necessary for the maintenance of life upon this planet, but that is quite another matter.

The least observant among us must have been impressed at some time or other with what we might term the cycle of life. Commencing with the dry corn seed falling into the earth, we see the plant grow and bring forth grain, some of which when dried is kept to be planted in the earth next season, and so on. Here we might speak of an active life and an inactive life. In the former condition the plant must continue to breathe and to absorb moisture or it will die, but in the inactive condition the dried seed may be kept for several years and yet be transformed into a living plant when placed in the earth.

Some years ago there was a rumour concerning a seed which had been found within the wrappings of an Egyptian mummy. The seed had been lying in an inactive state for thousands of years, and it was reported that when this ancient seed was planted it showed signs of life and growth. However, this report was contradicted later, and it is believed that there was some error in saying that this particular seed did germinate. Any farmer will tell you that corn seed deteriorates, that he always uses last year's seed, and indeed there seems no doubt that after a time a seed will lose the life contained within it.

There is a remarkable case—well authenticated—in connection with the spores, or seeds, of bacteria. These spores behave in a similar way to dried corn seeds;

they remain inactive until placed in a medium suitable for growth. Some spores laid aside by Pasteur were, after thirty years of inaction, placed in a suitable medium, whereupon they developed into bacteria. It is well known that some species of small worms may be dried and kept for a long time in this inactive condition—apparently dead—and yet become actively alive when placed in water.

Even last year's corn seed appears as lifeless as a chip of straw; wherein lies the difference? We can analyse the corn seed into all the elementary substances which form it, and we see a wonderful design in the arrangement of these elements, so that they are ready to hand when they are called for by the heat and moisture of the earth. We know how the seed once planted shoots arms down into the ground to absorb nourishment, and other arms up into the air to receive the stimulus of the æther waves of light and radiant heat. But we may examine the dried grain of corn with all our modern methods, and yet we can find no answer there as to the source of its life.

Granted that we once have life in any form upon this planet our chief mystery vanishes, for it is most apparent that life begets life. If it be true that there can be no life without antecedent life, then how did life originate upon this planet! The late Lord Kelvin believed that through all space and time life proceeds from life and from nothing else. In an address which this great thinker delivered to the British Association about forty years ago he said, "The hypothesis that

life originated on this Earth through moss-grown fragments from the ruins of another world, may seem wild and visionary. All I maintain is, that it is not unscientific."

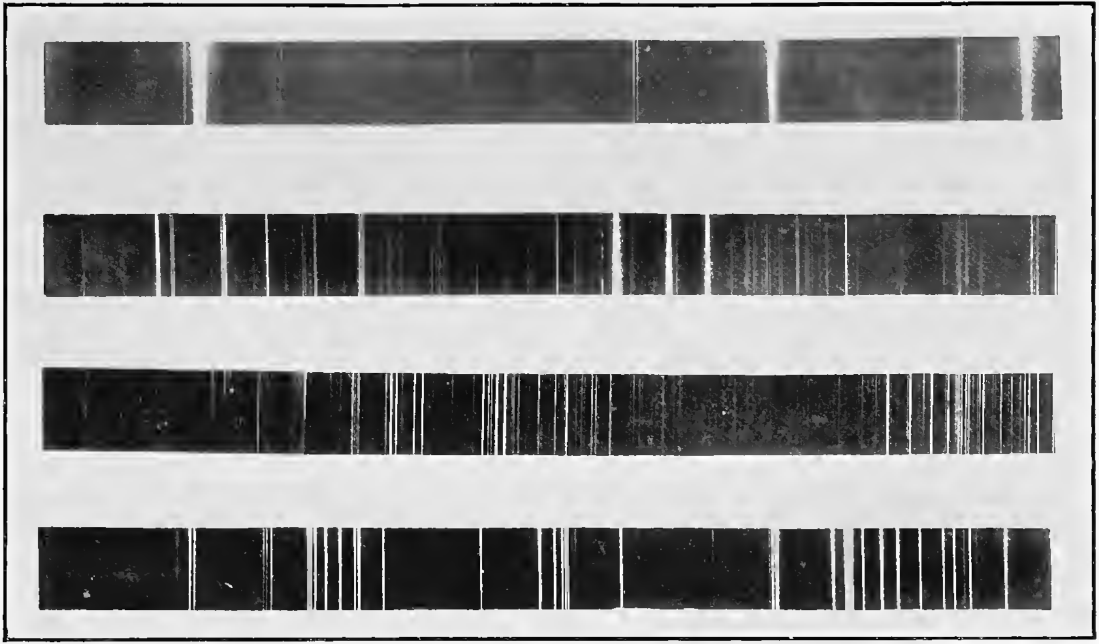
Long ago when people found living maggots on putrefying flesh they jumped to the conclusion that the insect's life originated in the decomposition of the flesh. Simple experiments soon proved that the maggots resulted from eggs laid in the flesh by flies. The world-famed Pasteur, with the aid of a powerful microscope, was able to show that putrefaction itself was due to living organisms, which we describe as microbes or bacteria. These bacteria increase at an enormous rate in favourable circumstances, but they follow the principle—life begets life. When there is fear of infectious disease we sterilise our milk so that any bacteria contained in it may be killed. In bringing butcher-meat from our distant colonies we defy the microbes of putrefaction by freezing them to death. When the meat is removed from the freezing chamber, no microbes can be originated within it, but living microbes, carried to it by the air, may make fresh attacks upon it.

Meat-jellies, or bouillons, are splendid breeding grounds for bacteria, but if these substances are thoroughly sterilised and hermetically sealed no bacteria can possibly appear in them. A few years ago we heard rumours that life had been originated in sterilised bouillon by the action of radium, but this is more than the experimenter himself really claimed.

He believed he had found a link between not-living and living matter, but his experiments leave us no nearer a solution of the problem before us—Whence came life?

There is a very definite idea that life originated in the sea. It is certain that the elementary constituents of sea-water and air are the same as those contained in our own bodies, the best known of these being oxygen, nitrogen, carbon, hydrogen, and sodium. Although this indicates the place wherein life originated, it still leaves us in the dark as to the origin of life. It is interesting to note that in the first chapter of Genesis we read, "Let the waters bring forth abundantly the moving creatures that hath life, and fowl that may fly above the earth in the open firmament of heaven."

Man has found out a great deal about the nature of life. The microscope has revealed the fact that all living things are composed of very minute cells. Man is composed of many trillions of such cells, but on the other hand there are living things composed of one cell only. But of what are those living cells made? They are made of a substance known as *protoplasm*, from the Greek *proto*, first, and *plasso*, I mould. This substance is entirely structureless, and is composed chiefly of carbon, oxygen, hydrogen, and nitrogen. We have seen that these are the chief constituents of our own bodies. We may picture the protoplasm forming cells just as atoms form molecules; we have a variety of molecules, and we have a variety of cells.



SPECTRA OF DIFFERENT ELEMENTS

These photographs were obtained by burning different elements in an electric arc, and photographing the light through a spectroscope. Each element has a distinctive series of lines. Only part of the spectrum is shown above. These photographs were taken in the late Lord Blythswood's laboratory.

We see that a study of living matter, as far as we can go, is really a study of chemical physics.

One thing has become clear from a study of the simplest living organisms. They move and act only because of outside influences; they simply react. They are affected by chemicals in their environment, by vibrations in the air, or by waves in the surrounding æther. The same truth holds good in man himself, but we are such infinitely complex agglomerations of cells that the resulting actions are difficult to trace.

However, what interests us at present is that to trace the origin of life we may confine our attention to protoplasm, as no serious thinker will doubt the plain truths of evolution.

A few devout thinkers of the present day do not think it wise to be so dogmatic as to say that it will be for ever impossible to originate life in the laboratory. Suppose for a moment that we should accomplish this seeming impossibility, man will not have become a creator, he will only have discovered the methods of the great Creator. To discover the way in which a machine is working is a totally different thing from making the machine. At present man places certain quantities of different elementary atoms together, heats them, and forms complex molecules, but man has not created these. To create is to make out of nothing. If the chemist or the biologist succeeds in making protoplasm artificially, our religious convictions need be shaken in no way.

CHAPTER XVIII

MORE ELECTRON IDEAS

A real connection between sun-spots and aurora and magnetic storms—The connecting link—Why aurora are only seen towards the poles of the Earth—How does the Earth come to be negatively charged—Atmospheric electricity—Lightning—What constitutes the Earth a magnet?—Magnetic storms—How a cold nebula may emit light—Why does the Earth's electric charge not increase?

It is curious that although sun-spots appear to us as dark holes in the Sun's photosphere, they are in reality as bright as the light from a lime-light lantern. The lime-light, as it issues from the lantern, is so bright that we cannot look directly at it, nor can we look directly at the Sun except through a dark glass. If the lime-light were placed in front of the Sun, and both viewed through a dark glass, the lime-light would look like a black spot.

The number of spots on the Sun varies from time to time; there are weeks together when none are seen, and also a maximum when more are seen than at any other time. The interval between two maximum periods is about eleven years. For a long time back we have been told that these variations of the sun-spots affect the magnetic condition of our Earth, and also that the number of those beautiful auroras

seen in the heavens varies with the number of spots on the Sun. Some have even endeavoured to prove that there is a real connection between the recurring eleven years of sun-spot maxima and the variation of grain prices. However, we shall be content to deal with the first two statements.

Observations have proved clearly that, when the sun-spots are most numerous, auroras and magnetic disturbances are also most numerous. And when any exceptional disturbance occurs upon the Sun we have corresponding effects upon this planet in brilliant displays of aurora and energetic magnetic storms, which latter are a source of considerable trouble in the working of our telegraphs.

What interests us at present is to see wherein lies the connection between the sun-spots and those phenomena on the Earth. Once more the obliging electron puts in an appearance, if we can speak thus of what is invisible. The Sun, like all other incandescent bodies, is allowing electrons to escape from it. The dissociation of the Sun is so great that we may picture continuous streams of electrons being shot off into the surrounding vacuum, and these will be greatest when there are great outbursts through large sun-spots. We therefore picture a gigantic cathode stream of electrons issuing from the Sun. We recollect that the cathode rays are invisible, but we know that when they pass through the rarefied air of a so-called vacuum tube there is a beautiful glow produced in the tube. We should expect, therefore, that the gigantic cathode stream from the Sun

would cause the upper rarefied air of our atmosphere to glow in a similar fashion. But we remember that in the laboratory the cathode stream was deflected by a magnet, and as the Earth is a huge magnet, we are not surprised to find that the Sun's cathode rays are deflected so that they do not enter the atmosphere at the tropics, but gradually descend towards the poles of the Earth. This is the reason why auroras occur continually at the poles of the Earth. Those occurring towards the north pole are called *aurora borealis,* and those seen within the region of the south pole are known as *aurora australis.*

We see that the Earth is a great sphere which is being bombarded continually with electrons, and we know that any body having an accumulation or surplus of electrons is negatively charged. Hence we have the solution of what must have been a puzzling problem to many of us in our boyhood; we wondered how the Earth should happen to be negatively electrified. This gigantic sphere—the Earth—charged with negative electricity gives us a very convenient standard of electric pressure, just as the sea-level gives us a convenient standard for height and depth. We make the Earth our zero of pressure.

We may picture the Earth as a great reservoir of electrons. If a body having a deficiency of electrons (a positively electrified body) is put in connection with the Earth, there will be a flow of electrons from the reservoir to the body referred to until there is an exact balance within its atoms between the electrons

and their enclosing spheres of positive electricity. On the other hand, if a body has an excess of electrons (a negatively electrified body), and if it is put in connection with the Earth, the body referred to will discharge its surplus electrons into the great reservoir until there exists an equilibrium within its atoms. Taking water as an analogy of the electrons, we know that water will flow out of a vessel above sea-level into the sea, whereas water will flow from the sea into a vessel below sea-level.

But some one may say that the electrons, shot at the Earth by the Sun, will be waylaid by our atmosphere. So they will, and they will ionise the air, or in other words, they will cause the electro-positive and the electro-negative atoms forming some of the molecules of atmospheric gases to split partnership. We shall try to picture what will take place in ionised air. Water vapour condenses more easily upon the electro-negative atoms, clouds will be formed, and when these ultimately fall in the form of rain, they will bring down the entrapped electrons with them, leaving the upper air positively electrified. In this way we have a reasonable explanation of the electrical conditions which we find in the atmosphere.

With the same facts before us, we can see how clouds may become at times highly charged with a surplus of electrons, so that there is a lightning discharge from one cloud to another, or between a cloud and the great reservoir—the Earth.

Another question which must have arisen in the minds of many thoughtful readers is, How did the Earth become a magnet? No one can doubt that the Earth is a magnet; its influence upon magnetic needles is most apparent. As natural magnets, or *lodestones*, are found in the Earth, some one might jump to the conclusion that the presence of these would constitute the Earth a magnet. Upon further consideration such an one would find that this was not a reasonable conclusion. Lodestone is found only in a limited number of places, and in no very great quantities. When the inquirer learned that railway lines and iron railings placed in certain positions are found often to be magnetised by the influence of the Earth, he would be willing to conclude that lodestone is nothing more than certain iron ores magnetised in the same manner. How, then, did the Earth become a magnet?

It is true that the Earth is a huge electrically charged sphere, and that it is constantly rotating at a rapid rate upon its axis, and we have experimental proof that under such circumstances a sphere would have a weak magnetic field at its surface. Calculations, however, show that this is certainly not the cause of the Earth's magnetic field; it is capable only of accounting for the merest fraction of the force present. The chief factor appears to be electron currents within the Earth's crust. If we were asked what physical condition could cause a movement of electrons within the Earth, we should think at once of differences of

temperature in connection with *thermo-electricity*. It is not necessary to think of a junction of two dissimilar metals being subjected to heat to produce an electron current. We know that even a difference of temperature in the same piece of metal will cause a locomotion of electrons. Without going into the detail of the subject, it may be stated that there are conditions which account for a real thermo-electric current in the Earth's surface. At the same time it must be admitted that although this electron current is the most reasonable explanation of the Earth's magnetism, we have no direct proof of this theory.

There is one thing I should like to point out in connection with the foregoing. If the Earth's magnetism is due to a temperature gradient in the surface of the Earth, one would expect that the magnetic field would vary during the day. It is a well-known fact that such variations do take place, commencing with a minimum in the morning, rising to a maximum about mid-day, decreasing till the evening, and remaining constant during the night.

There is no doubt that this electron current in the Earth's surface would be appreciably affected by any exceptional streams of electrons approaching the Earth from the Sun. Hence the connection between magnetic storms and the outbursts of sun-spots.

Certain wireless messages received in the spectro-

scope from vast nebulæ[1] have been interpreted by some scientists to indicate that the nebulæ are cold bodies; this message could not be understood. How could a cold body emit light? We see a cold rarefied gas glowing in the well-known vacuum tubes when streams of electrons pass through them. As the Sun and all stars are sending streams of electrons out in all directions into the surrounding vacuum, some of these would be intercepted by a gaseous nebula. Here again the versatile electron helps us out of a difficulty.

In closing this chapter it occurs to me that a difficulty may arise in the minds of some readers in connection with the continuous bombardment of the Earth by electrons. Surely the Earth's negative electrification will be continuously increasing? It will be of interest to see how this does not happen.

We know that electrons will be discharged from a negatively charged body—such as the Earth—to a positively charged body—such as the Sun. This is the reverse of what we have been considering. But how can electrons be sent both ways? Only by two different forces. Electrons will go from the Earth to the Sun by *electric* pressure, the difference of pressure between these two bodies being about one billion volts. But the electrons which come from the Sun to the Earth do not move under electric pressure;

[1] These nebulæ are quite a different class from the nebulæ we considered in an earlier chapter, and which were composed of meteorites.

they travel, as we saw in a previous chapter, under the mechanical pressure of light. In this way a proper balance is maintained, and a continual passage of electrons kept up. We see, as it were, a circular dance of electrons throughout the solar system.

CHAPTER XIX

WHAT ARE THE X-RAYS?

Are the X-rays waves in the æther?—How the X-rays were discovered—How they are produced—The new photography—What interested the world—What the X-rays are not—Our present ideas of their nature

We have become familiar with the idea of æther waves, some of which affect our vision, others heat our bodies, some affect the detector of a wireless telegraph receiver, while others which do not affect our vision will act upon the chemicals on an ordinary photographic plate. All these are electro-magnetic waves in the æther. Are the X-rays to be included in the same category? If so, we should be able to reflect, refract, and polarise them, just as we found we could do with all the æther waves already mentioned. But we cannot do these things with X-rays. At first some experimenters believed they had succeeded in reflecting them, while others thought they had polarised them with the aid of tourmalines, but in every case it was found, upon further investigation, that these supposed effects were due to some error. It is clear that whatever the X-rays may be, they are not regular trains of electro-magnetic waves, such as light is.

It will simplify matters if we consider the method

of producing X-rays, and it will be of interest to see also how these were discovered. Needless to say, they were not invented any more than electricity was invented; the X-rays had been shooting forth from vacuum tubes for nearly twenty years before man was aware of their presence.

Professor Röntgen was experimenting in 1895, like a great many other physicists, with vacuum tubes. He intended following up the experiments of Lenard, who had succeeded in tracing the cathode rays outside of the vacuum tube. In the physical laboratory of the University of Würzburg (Bavaria) Professor Röntgen was well supplied with modern apparatus, and with excellent means of producing very high vacua in tubes. The Germans excel in this class of work.

Röntgen had enclosed a vacuum tube within a shield of black cardboard, which prevented any light escaping from the phosphorescing glass of the tube. Lenard had used a fluorescent screen to trace the escaped cathode rays, and Röntgen had a similar screen beside him on this occasion. These screens[1] had been in use for a generation in connection with ultra-violet light.

[1] Some substances continue to emit light after the exciting force has been withdrawn; we call these *phosphorescent* substances. Sulphide of zinc, which is used in luminous paints, is a phosphorescent substance. Some other substances only emit light as long as they are being subjected to the exciting force; we call these *fluorescent* substances. Barium platino-cyanide is a fluorescent substance, and its electrons are affected by the invisible short ultra-violet rays, and also by the X-rays. The fine chemical crystals fluoresce only as long as the invisible rays keep falling upon them.

When Professor Röntgen passed an electrical discharge through the hidden tube he observed that his fluorescent screen, which was lying on the table, became luminous. It was apparent that this luminosity could not be excited by any ultra-violet waves, for the black shield surrounding the tube was quite opaque to ultra-violet light. Even an arc lamp, which is very rich in ultra-violet rays, was completely shielded by such a shield. When Röntgen was asked later what he thought when he made this observation, he said: "I did not think; I investigated."

Röntgen found that these new rays had a remarkable power of penetration. Many substances, such as wood and leather, which were opaque to light, were fairly transparent to these new rays. The denser a body was, the greater was its resistance to the passage of the rays. The one thing, which arrested the attention of the general public, was the fact that the living skeleton could be viewed upon the fluorescent screen. When Professor Röntgen found that metal weights could be seen through a wooden box, it would be a natural thing to try how his hand would appear, if indeed he did not observe the bones of his fingers when placing objects behind the screen.

It may be well at this moment to consider the method of producing the X-rays, and of using the fluorescent screen, although to most of us these things are quite familiar. The electric current from an accumulator or from the main is passed through an induction coil; perhaps some may know it better

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AN X RAY PHOTOGRAPH OF A CAMEO

The left-hand illustration is an ordinary photograph of a cameo, while the right-hand illustration is a Röntgen ray photograph of the same cameo. This shows how the invisible rays have penetrated the cameo and reached the photographic plate beneath it. The different parts of the cameo have offered different degrees of resistance to the penetrating rays.

under the guise of a sparking coil. A special vacuum tube is connected to the terminals of the coil, so that a discharge will take place between the two electrodes within the tube. In the accompanying diagram it will be seen that the cathode is saucer-shaped, in order to focus the cathode stream upon a metal target placed about the centre of the tube. This target may or may not form the other electrode of the tube. However, we do not mean to trouble with detail; we wish to see what it is that gives rise to the X-rays.

When the electric current is passed through the tube the stream of electrons strikes the metal target, and in doing so they produce a sharp, sudden splash in the æther. These were spoken of, at first, as æther waves, some thinking that they were longer than the infra-red waves, while others believed they were shorter than ultra-violet waves. The idea of to-day is that the X-rays do not constitute a regular train of waves at all, but that they are very thin pulses of intense electric and magnetic force.

The little target within the tube is placed at an angle, so that when it is bombarded by the electrons the æther pulses or X-rays will be deflected out at the side of the tube, as suggested by the diagram.

The fluorescent screen has the fine barium platino-cyanide crystals on the one side of the screen, the back of which is covered with a black cloth lining. The back of the screen is turned towards the tube so that the X-rays fall upon the black lining, which offers practically no resistance to their passage. The rays

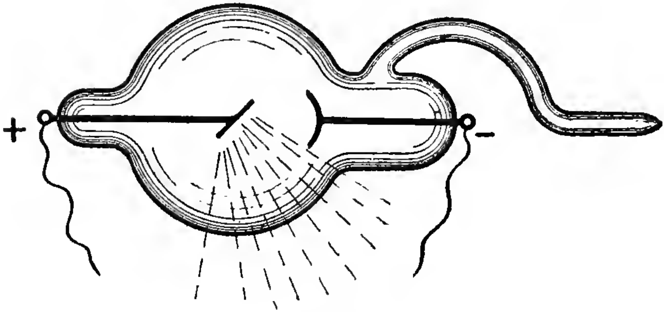


FIG. *D*

A Röntgen-ray Tube

This diagram represents a single form of X-ray tube. The stream of electrons, or negative current, passes from the cathode (−) to the anode (+). We picture the electrons being shot off from the cathode with great energy, and as the cathode is saucer-shaped the stream will be focused on to the target, which is seen lying at an angle. When the electrons are suddenly stopped by the target they produce a sort of splash or pulse in the surrounding æther, as indicated by the dotted lines. This æther disturbance is what we know as Röntgen-rays, the properties of which are explained in the text.

penetrate the parchment of the screen, and cause the chemical surface to fluoresce. If the hand is placed flat against the back of the screen, the rays will penetrate the flesh much more easily than they can penetrate the bones, so that the bones are clearly seen upon the screen. For our present purpose we need not consider the great value that Röntgen's discovery has proved to the surgeon.

Röntgen was not long in trying if these new rays would affect a photographic plate, and the world was soon talking about the new photography. The idea of taking a photograph of the living skeleton upon an ordinary photographic plate, and doing so in the dark without even opening the dark slide or envelope enclosing the sensitive plate, was indeed something to talk about. In the illustration facing page 268 we see an ordinary photograph of a cameo, and alongside of this we see a radiograph taken by X-rays. This shows how the X-rays have penetrated some parts of the cameo more easily than other parts.

What concerns us at present is the scientific ideas concerning the X-rays. Scientific men had become familiar with the cathode rays or streams of electrons, and with the Lenard rays, which are really the cathode rays that have escaped through an aluminium window in the tube. We have seen in an earlier chapter the great value of Lenard's experiment to the scientific man, but it would seem of no importance to the man-in-the-street. Nor would the outsider have been interested specially in the discovery of the X-rays but

for the eeriness of being able to see and photograph the living skeleton.

It will be noticed that our knowledge of the nature of the X-rays is chiefly of a negative character. We know that they are not a stream of electrons like the cathode and the Lenard rays, for the X-rays cannot be deflected by a magnet. We know that they are not æther waves of the nature of light, as X-rays cannot be reflected, refracted, or polarised.

We see very clearly what the X-rays are *not*, and the best that can be said as to their nature is that they are thin shells or pulses of intense electric and magnetic force. It may be that the scientific world of to-morrow will not be satisfied with this statement. As a looker-on I have wondered sometimes if the X-rays may not prove to be the electrons breaking up, just as we find the electrons to be produced by the atoms breaking up. If Mendeléeff's theory turn out to be true—that the æther is composed of particles—and if those particles form the electrons, may the X-rays not be the escaping æther particles expelled from the electron in its collision with the target in the X-ray tube? In any case the greater the collision (*i.e.* the more abruptly the electrons are stopped), the more energy is exhibited in the form of X-rays.

CHAPTER XX

HOW RADIUM WAS DISCOVERED

The public's overestimate of radium—What led up to Madame Curie's great discovery—A Russian experiment—Becquerel's discovery of uranium rays—Similarity of circumstances with Daguerre's discovery—Are the uranium rays the same as X-rays?—The Curies' work—Public interest in radium—Physiological effects—The action of the spinthariscope—Heat evolved by radium—Photographic effects—The Birth of radium

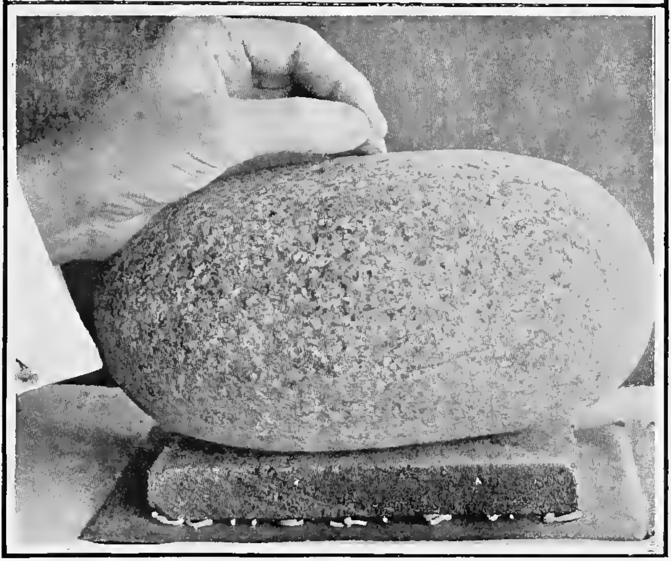
It seems but as yesterday that Radium was discovered, and yet it is more than ten years since Madame Curie, wife of the late Professor Curie, of Paris, brought to light this element which had lain hidden in the world for millions of years.

Although this great discovery was made in 1898, it was several years later that the general public became interested in it. Rumours went abroad that this new element was going to revolutionise the workaday world. All our existing methods of obtaining energy were to go to the wall, incurable diseases were to be cured, and the very foundations of physical science were to be demolished. This was quite enough to arouse general interest, but it must be clearly understood that the scientific world did not share in these prophecies. Indeed we shall see that men of science were familiar with radio-active bodies before the dis-

covery of radium, although its forerunners were much less active. Sir Oliver Lodge put the matter very clearly at the time in this way—"A bare fact is nothing, or little, till it is clad in theory. Sometimes a fact is born before its clothes are ready. Sometimes a 'layette' has been provided before a fact is born. Radium is in the latter predicament. No fact concerning radium need stand out in the cold for lack of theoretic shelter."

Men of science do not stumble over discoveries by mere chance; there is always a train of facts leading up to each discovery. It will be of interest to see what led up to the unearthing of radium. One would not think that there was any connection between Sir William Crookes' discovery of the cathode rays produced in vacuum tubes and the discovery of radium, and yet there is a straight line of descent. Then again we could trace the lineage of Crookes' discovery away back to the first rubbing of a piece of amber in ancient times.

We have seen already that Crookes' experiments led to Röntgen's discovery of the X-rays. The fact that these invisible rays would affect a photographic plate led others to try if phosphorescent substances might not emit similar invisible radiations. But what connection is there between phosphorescent substances and X-rays? The X-rays cause the glass of the tube in which they are produced to phosphoresce, and they also excite phosphorescence in many gems and chemical crystals.



By permission of *Rebman Ltd., London (Archives of the Roentgen Ray)*

PHOTOGRAPHING THROUGH A GRANITE BOULDER

This experiment illustrates the wonderful penetrating power of radium rays. Pieces of lead wire were twisted into the form of the words seen in the upper illustration. These letters were laid upon a thick, light-proof envelope enclosing a photographic plate. On the top of these was laid a one-inch board, and on the top of that a six-inch boulder. A small glass tube containing some radium salts was laid on the top of the boulder. The rays penetrated the boulder, the wood, and the light-proof envelope, but were entrapped by the lead wire, and produced the photograph shown in the upper illustration. (Exposure three days.)

How Radium was Discovered

We all have some knowledge of phosphorescent substances. We know that luminous paints, which contain sulphide of calcium or sulphide of zinc, will shine in the dark for some time if previously exposed to sunlight. One practical adaptation of these luminous paints has been to put them on match-box cases, so that they will shine in the dark and indicate their whereabouts. Some of us may have boyhood recollections of rubbing a few drops of phosphoric oil upon our faces and hands to personate a real live ghost.

It occurred to a Russian scientist to try if the phosphorescent calcium sulphide could possibly affect a photographic plate through a thin sheet of aluminium, in the same way as Röntgen's X-rays had been able to do. Although the metals generally are opaque to X-rays, a thin sheet of aluminium is practically transparent to them. This experimenter, whose name—Niewenglowski—looks strange to us, made the following simple experiment. He protected a photographic plate under a sheet of aluminium, and on the top of this he placed some of the phosphorescent substance resting upon a small square of glass. He left this arrangement alone in the dark for one day and one night, and when he developed the plate he found that he had secured an image of the little square of glass upon which the phosphorescent substance had been lying, and there was unmistakable evidence that invisible rays had penetrated the thin sheet of aluminium. A closer examination showed that the penetrating rays

were not X-rays, for they had been refracted by the glass plate, as was evident at the edges. These rays consist of very penetrating rays of light. To the general reader they are of interest only as a stepping-stone between Röntgen's discovery and that of radium by Madame Curie.

The very same idea of some possible connection between X-rays and phosphorescence occurred independently to Professor Becquerel, of Paris. He tried the photographic effect of every phosphorescent substance he could think of, and during those experiments he found that certain uranium salts were very active in emitting radiations which affected a photographic plate. The curious thing was that those uranium salts scarcely deserved to be called phosphorescent at all. While luminous paint will shine for many hours after exposure to sunlight, these uranium salts will only phosphoresce for a very small fraction of a second after the light has been withdrawn. The ordinary man would have put these out of court without ever giving them a trial. But Becquerel desired to give them a fair trial, so he arranged that they might have an opportunity of acting upon a photographic plate while the salts were continuously exposed to sunlight. He secured a photographic plate within a light tight envelope, and he placed this in the sunlight with some crystals of uranium salts spread on the top of the black envelope. When he developed the photographic plate, he found that invisible rays had penetrated to the plate and had produced an image of the uranium crystals.

Becquerel arranged a second experiment, and this time he placed a metal cross between the uranium salt and the dark envelope which enclosed the sensitive plate. He intended exposing this to sunlight for some hours, just as he had done on the former occasion; but, as luck would have it, the sunshine vanished at the time it seemed most wanted. We shall see that this was a good fairy in disguise, for Becquerel put the experiment aside, leaving it arranged as described, and he intended to make a complete exposure when the Sun was more favourable. But for some reason or other he developed the photographic plate after it had lain aside without further exposure, and we may judge of his surprise when he found an image of the cross upon the plate. This could not have happened during the very short exposure of the uranium to sunlight. Could the photographic action have been going on without the exciting influence of the Sun upon the uranium salts? This could be proved by a repetition of the experiment without the aid of sunlight at all. This done, the same result was obtained in the dark. The invisible rays were not due to the phosphorescent property of the substance at all. Indeed there was no doubt that these invisible uranium rays were something quite new.

I think it is worth while, in passing, to note how parallel this case is with Daguerre's discovery of practical photography. Having prepared the surface of a polished silver plate by exposing it to the vapour of iodine, Daguerre set up his camera intending to expose

the plate for several hours in sunshine, in the hope of securing a picture. Just when everything was in readiness the Sun vanished, so Daguerre put his polished silver plate aside in his chemical cupboard, intending to repeat the experiment again at the Sun's pleasure. Imagine Daguerre's surprise when he went to take the plate from the cupboard next morning; he found a "perfect picture" upon it. It was clear that the very short exposure had impressed a hidden or latent image upon the plate, and that the vapour of some of the chemicals in the cupboard had produced the visible image. By experiment Daguerre found that the active agent had been the vapour of mercury, and in this way was practical photography discovered. These discoveries, Daguerre's and Becquerel's, which were both made in Paris, have always seemed to me to be parallel cases of so-called accidental discovery.

It was evident that the "Becquerel rays" emitted by uranium salts were quite independent of outside influences. To make assurance doubly sure, Becquerel prepared uranium salts from a solution in the dark, and they were found to act upon a photographic plate without the salts ever seeing the light of day. As time went on it was evident that the activity of uranium salts was continuous; they seemed to lose nothing by giving out these Becquerel rays. But are these radiations the same as X-rays?

At first it did seem as though the Becquerel rays were merely X-rays, but even had this turned out to be the case, the discovery would have been a great one.

Röntgen produced X-rays artificially in the laboratory; these rays were the result of definite electrical energy supplied from a known source. To find a natural substance continually producing X-rays, without the supply of energy from without, would be of infinitely greater interest from a scientific point of view.

Becquerel found that these uranium rays, which we have named after him, would discharge an electrified body just as X-rays will do. The rays of uranium would penetrate the same substances as X-rays, and the former could not be reflected, refracted, or polarised, so that in all these respects they were alike to X-rays. But we shall see that they are not X-rays. However, we must not lose sight of the primary importance of Becquerel's discovery; a certain substance in its natural condition is continually producing invisible radiations.

It was only natural that other experimenters should make investigations to find out if any other substances would act in the same way as uranium, which, by the way, is the heaviest of all the elements. A very important line of investigation was begun by Professor and Madame Curie, evidently with the idea of making sure that the radio-activity was due to the uranium itself and not to any impurities contained in it. When experimenting with different specimens of pitchblende, a natural mineral substance from which uranium is obtained, the Curies found that some specimens of the pitchblende were more radio-active than uranium itself. This proved that the radio-active properties of

the pitchblende were not due really to the uranium itself. It may be remarked that it was shown later that pure uranium salts, freshly precipitated, were not radio-active. Still later it was found that in time these salts became radio-active, but we had better take the stepping-stones as they come.

The Curies were determined to lay by the heels the one thing which was producing the radio-active phenomena. By well-known chemical processes they sifted out the different ingredients of the pitchblende. It is interesting to note that the Curies were positive that the really active substance for which they were seeking was not in the uranium itself, for they set to work on a large scale with pitchblende "tailings," from which the uranium had been extracted for commercial purposes, such as the colouring of Bohemian glass.

The Austrian Government placed many tons of these tailings at the disposal of the Curies, who erected refining works on the outskirts of Paris. There was no idea of obtaining radio-active elements on a commercial scale; it was evident already that whatever substance was producing the phenomena of radio-activity it must exist only in a very small quantity. By painstaking chemical analysis the Curies separated three different radio-active substances, but one of these elements was found in greater quantity than the other two, if one may use the word quantity at all in connection with these radio-active substances. The whole radio-active products from eight tons of pitchblende

could be carried on a threepenny piece. The chief radio-active product was christened *Radium* by Madame Curie.

There was no comparison whatever between the radio-activity of uranium and that of radium; the latter being estimated to be from one to two million times more active than uranium. This greatly increased radio-activity gave men of science a much better chance of finding out what the radiations really were.

One thing which seemed to interest the public was the exorbitant prices asked for specimens of radium, but the price is not to be wondered at when one considers the great amount of labour in extracting the radium. When the man-in-the-street heard that radium cost three thousand times the price of gold, he was naturally interested. However, he would be somewhat disappointed when informed that there was less radium in pitchblende than there is gold in solution in sea-water.

Another point that interested the public was the fact that radium had a decided effect upon the human body. Professor Becquerel discovered this to his own discomfort. He had carried a small specimen of radium in a case in his waistcoat pocket, while he came over to London to deliver a lecture, and in about a fortnight's time he found that the flesh under this pocket was beginning to redden, then followed a painful sore which took many weeks to heal. Professor Curie also observed that his hands were injured some time after delivering a lecture at the Royal Institution

(London), during which he had been handling some radium. This is not altogether surprising when we consider the well-known physiological effects produced by X-rays. However, the man-in-the-street was carried away with the idea that at last a panacea for all ills had been discovered.

During the first few years of the present century every one was interested in radium. What the metal radium looks like we cannot say, as no one has seen it yet; we only know it in its compounds. We can get its atoms in partnership with chlorine atoms, forming radium chloride, or with atoms of bromine, forming radium bromide. These radium salts have very much the same appearance as common salt, but they emit a very feeble light in the dark. The luminous effects seen in the small spinthariscope, or spark-viewers, sold by opticians, are due to the radiations from radium bombarding a phosphorescent screen. But how can opticians afford to sell, for a few shillings, instruments containing so precious a substance as radium? This we shall understand by considering the construction of the instruments. This scientific toy, invented by Sir William Crookes, consists of a short brass tube having a magnifying glass at one end and a small phosphorescent screen at the other end, while in front of this screen and close to it is fixed a tiny piece of wire which has been dipped in a solution of radium salts. The very minute quantity of the salts adhering to the wire is sufficient to produce a very active bombardment of the screen.

The effect, which no doubt many readers have seen, is somewhat like a turbulent luminous sea. It has been described by some as a swamp full of fireflies, or as scintillating stars on a clear night. Others, when looking into the spinthariscope, say that they see splashes of light at the centre of the screen and sparks towards its edge.

Whenever one chooses to pick up a spinthariscope and look into it, one sees the continual bombardment proceeding. One might imagine those sparks as saying—"Men may come and men may go, but we go on for ever." But we shall see later that the "for ever" can only be used with some poetical license.

Before inquiring what these radiations of radium consist of, it will be of interest to note another peculiar property of this recently discovered element.

If any object in a room stands at a higher temperature than the surrounding air, we know that the body has been heated by some artificial means. If we find it gradually cooling, we know that the source of heat has been withdrawn, but if we find it maintaining constantly a temperature above that of its surroundings, we know that it is in connection with some source of heat. In other words, we know that energy is being supplied to it. The household cat feels nice and warm on a cold day, but we know that the heat is maintained only at the expense of chemical energy within the cat's body. If we were so cruel as to starve the cat, and thus stop the chemical

actions, we should find the cat's temperature to decrease gradually until the animal died, whereupon its temperature would quickly reach the same as that of the surrounding air. Radium appeared to contradict this general rule ; it remains about two degrees hotter than its surroundings. The heat, however, is due to the expenditure of internal energy, as we shall see in the following chapter.

We have witnessed the photographic effects of uranium salts, and, as we should surmise, the salts of radium are still more active in this direction. Some very clear radiographs have been obtained by the radiations of radium.

Any one who cares may see the spectrum of sodium in a pocket spectroscope, as one has only to burn a little common salt and view the flame. Few of us need hope to see the spectrum of radium, as it is too precious a substance to treat often in this fashion. The spectrum has been produced, and it is, of course, distinct from that of any other known element.

I had written down "The Birth of Radium" as the title of this chapter, but I feared that a casual glance might give one the impression that Radium was born in 1898. However, we shall see some facts regarding the birth of radium in the course of the following chapters.

CHAPTER XXI

WHAT ARE THE RAYS FROM RADIUM?

The pioneer investigators—An important discovery—Three different kinds of rays—The properties of each—Their nature—A record velocity for material particles—The source of radium's heat—Enormous expulsion of material particles from radium—Infectious radio-activity—A gas given off by radium—A striking experiment—Liquefying the invisible—Disappearance of the emanation gas

IN the preceding chapter we have become familiar with the properties of radium, but it will be of special interest to see of what the rays of radium really consist. We have seen that the uranium rays appeared to be very similar to the X-rays, but with the more active radiations from radium it became much easier to test the nature of the rays.

Up to this point we have been dealing with the work of French scientists, almost exclusively, and to them belongs the honour of this great discovery of radio-activity. But now we come to the unravelling of the mystery, and in this we are proud to think that our own countrymen have taken a very active part. Professor Rutherford and Mr. Soddy at Montreal, and Sir William Ramsay, and again Mr. Soddy in London, were among the pioneers who investigated the nature of radio-activity.

At the outset a very important discovery was made by Rutherford. He found that there were three distinctly different radiations given off simultaneously, and he labelled these with the three first letters of the Greek alphabet—Alpha (α), Beta (β), and Gamma (γ). He found the alpha rays had only a very small penetrating power, and could be stopped by a sheet of notepaper. And while the beta rays could penetrate a thin sheet of aluminium, the gamma rays required a fairly thick sheet of steel or lead to stop them. Looking at this one property of penetration alone, we could form a very fair idea as to the nature of these three different kinds of rays.

To begin with the gamma rays, we should guess that these must be Röntgen rays from their intensely penetrating power. Then, remembering Professor Lenard's experiment with the aluminium window through which the cathode particles escaped, we should say that the beta rays were the same well-known electrons, as they succeeded also in penetrating a thin sheet of aluminium and yet are stopped by a sheet of metal which the Röntgen rays can penetrate. We have only the alpha rays left for consideration, and we should guess that these must be invisible atoms of matter, as they fail even to penetrate a sheet of notepaper.

If we had arrived at the foregoing conclusions we should find that we had no occasion to alter our ideas. These are confirmed by other investigators, and there remains little doubt regarding the nature of these three radiations.

If the gamma rays are really Röntgen rays, they should affect a photographic plate after passing through objects which are transparent to X-rays; experiment proves that they do. They should also discharge an electrified body as the X-rays do, and this condition they fulfil also. If the gamma rays are X-rays they should not be deflected by any magnetic field, as we have failed to deflect X-rays; this test is also confirmative. Hence we feel quite confident that the gamma rays emitted by radium are really the well-known Röntgen rays. But our previous knowledge of X-rays has been that they were caused by the sudden stoppage of flying electrons. Theory informs us that X-rays should be produced also by the sudden starting of electrons; our difficulty in practice is that we cannot start them with sufficient suddenness to make a splash in the æther. But if the beta rays are really electrons, and if they start with sufficient suddenness, we can account for the presence of X-rays. We shall see that these two "ifs" disappear, in the following paragraph concerning the beta rays.

We have seen that the beta rays behave like flying electrons in being able to pass through a sheet of aluminium foil. Electrons are charges of negative electricity, and we have seen in an earlier chapter that they are deflected easily by a magnetic field. The beta rays stand this test, and they also prove themselves to be negatively charged particles. Their speed has been calculated from their magnetic deflection, and it is found that some of them are travelling at enormous

speeds; about one hundred thousand miles per second. We therefore feel justified in saying that these electrons are expelled with sufficient suddenness to produce the gamma or Röntgen rays. As the velocity of beta rays is considerably greater than that of electrons within a vacuum tube, we are not surprised to learn that the beta rays can penetrate a greater thickness of aluminium than the Lenard rays can. Many other tests have been applied to the beta radiations, and there is left no shadow of doubt as to their identity with the electrons of which we have seen so much in the preceding chapters.

How will it be possible to test the nature of the alpha rays? We have surmised that they are atoms of matter as they are imprisoned by a sheet of note-paper, and we are fortunate in finding that they are deflected by a magnetic field. They are deflected in the opposite direction from the electrons, and we know from this fact that they must be oppositely electrified, or, in other words, that they must carry a charge of positive electricity. Their positive charge is easily demonstrated by enclosing the radium in a metal box, from which these alpha particles cannot escape. We find that the inside surface of the box becomes charged with positive electricity, while the negative electrons have escaped through the box, and may be traced outside. As already explained, these electrons have a greater penetrative power than the electrons within a vacuum tube. Referring again to the alpha particles, we shall see later

that these are really atoms of a very light gas called *helium*.

These alpha particles are expelled at a velocity of twenty thousand miles per second, which beats all previous records for particles of matter. Indeed there is no comparison between this and the fastest moving body we can think of. Of course the race is a very short one, for they are soon picked up by the molecules of the gaseous mixture which we call the atmosphere.

The prodigious speed of those helium atoms is quite sufficient to account for the energetic bombardment witnessed in the spinthariscope, as described in the preceding chapter. It must be remembered that these atoms are miniature in the extreme. Look at the full stop at the end of the preceding sentence and try to imagine a regiment of atoms standing shoulder to shoulder right across the diameter of that dot. There would be no less than five million helium atoms required to form that tiny line. The picture is beyond our powers of imagination.

The remarkable property, which radium possesses, of keeping up a constant temperature greater than that of the surrounding air, is accounted for by the alpha particles, *alias* the helium atoms. Picture a gramme of radium salts, which is about as much as you could conveniently heap up on a threepenny piece. From this quantity there are expelled no less than one hundred thousand million helium atoms per second. It is difficult to realise what this means, but if the

helium atoms expelled in one single second could be divided equally among the population of the whole world, we should each receive about fifty thousand. At the end of the first minute each person in the world would possess about three million helium atoms, and the total possession of each person at the end of the first day would amount to thousands of millions. Think of all this vast amount of helium atoms being expelled from less than half a teaspoonful of radium salts in a single day. And yet this discharge of material atoms goes on incessantly year in and year out for many centuries. The energy carried by these flying atoms accounts for ninety-nine per cent. of the total energy emitted by radium. The temperature of radium is due to some of those atoms bombarding the radium itself in their attempts to escape into the air.

From the foregoing paragraph it will be seen that the flying electrons (beta rays) and the Röntgen rays (gamma rays) only represent about one per cent. of the energy emitted by radium. But both of these radiations will affect a photographic plate more actively than the helium atoms (alpha rays). Both the beta and gamma rays will discharge an electrified body, and will cause a phosphorescent screen to become luminous, but the splashes of light seen in the spinthariscope are due to the alpha rays or helium atoms.

At first, one is apt to get a little confused about the three different kinds of radiation. I find that the best way to fix their natures in one's mind is to take them alphabetically—alpha, beta, gamma—and then think

of them as becoming less and less materialistic. We set off with atoms of matter, then electrons, and last of all æther disturbances known as X-rays. This enables one to remember the different properties of the three radiations from radium.

The Curies soon observed that radio-activity was an infectious thing. Any substance remaining in the neighbourhood of radium became radio-active also, but not permanently so. These *acquired* radio-active effects last for several hours, and in some cases for days. It was observed that as soon as the presence of the radium was withdrawn, the infected substance began to lose its acquired properties. It is interesting to note that the observer himself became radio-active, and his presence was sufficient to discharge electrified bodies, and to affect his electrical measuring instruments. He might try to wash his hands of this acquired property, in a literal sense, but without success. Professor Curie had reason to be thankful that this acquired property was not permanent; otherwise his further experimenting, with delicate electrical measuring apparatus, would have been impossible.

At first this acquired radio-activity could not be understood, but further experiments shed an interesting light upon this phenomenon. It was found that if the radium salts were dissolved, or if they were heated, their radio-activity was much more infectious. A neighbouring body became radio-active even when sheltered from all the three kinds of radiations already mentioned.

A very simple experiment proved that the acquired radio-activity was not due to the radiations of radium. A solution of radium salts was placed in a glass bulb, while some phosphorescent substance was placed in a second bulb. The two glass bulbs were then connected by means of a bent glass tube, so that none of the rays could possibly get from the radium bulb to the phosphorescent bulb, for none of the radiations can turn a corner. A stopcock was placed in the connecting tube, so that nothing could pass from the one bulb to the other as long as it was closed. When the apparatus was taken into the dark, nothing was seen until the stopcock was opened, whereupon the phosphorescent substance became luminous. This indicated that some radio-active gas had travelled from the radium salts to the second bulb. Rutherford had found previously that a radio-active gas was given off by another radio-active element called *thorium*, but in that case the gas or *emanation* was very short-lived, disappearing in a few minutes. In the case of radium, it was found that the emanation remained radio-active for some weeks.[1]

It is interesting to be in the dark and to watch this emanation gas being drawn through a very long tube of phosphorescent glass. As the gas passes along the tube, the glass becomes luminous. In this way one witnesses the actual passage of the emanation from the radium solution to a distant receiver. Special interest is added if the receiving bulb, which

[1] The emanation gas must not be confused with the rays from radium.

is also phosphorescent, is placed in liquid air. It is quite apparent that the emanation gas liquefies when it reaches this intensely low temperature. We cannot pour out the liquid emanation as we can pour out liquid air. Indeed there is no liquid to be seen, as the quantity is so very small. Nevertheless we know that the emanation liquefies, for instead of the gas filling the bulb, we see from its phosphorescent effect that it accumulates at the bottom of the receiving bulb.

It is this emanation which makes its way to bodies placed in the neighbourhood of radium, and deposits some volatile solid upon them, making them temporarily radio-active. If the emanation is kept in a sealed tube, its radio-activity disappears in a few weeks.

There is a great deal of further interest connected with the emanation and the radiations of radium, but I fear to trouble the general reader with too much detail. There are some points, however, that will help us to answer the question which stands as the title of the following chapter, "Is the world going to pieces?"

few weeks. It is true that he can evaporate the solution and recover his radium salts, but these have only one-quarter of their previous radio-activity. Needless to say, the owner of the radium would not be so seemingly rash unless he were confident that the radium would regain its lost properties as quickly as the emanation, which he has abstracted, loses its activity.

Being convinced that the radium we treasure to-day will cease to exist as radium in a few thousand years, it is evident that the radium we now possess cannot have existed many thousands of years. Roughly speaking, we might say that the length of radium's life is between two and three thousand years. From whence, then, does it come ?

If the "man in the moon" dropped down upon this planet, and we handed him a bright red apple, he might think that it had existed always in the condition in which he saw it. But when he found it beginning to decay and waste away, he would probably conjecture that it was only a temporary form of matter. If he had dropped down into one of our cities where he could only see apples collected together in barrels, their origin might remain a mystery to him. If, however, in his subsequent walks abroad he found those apples upon certain trees and nowhere else, he would feel confident that he had discovered the parent of the apple. Where, then, do we find radium in Nature ?

Not only do we always find radium in those minerals which are richest in uranium, but there is always a definite relation between the quantity of uranium and

the quantity of radium in every kind of pitchblende. There seems to be no doubt that uranium is the parent of radium.

In tracing the genealogic tree downwards from uranium, which is the heaviest element, we find some interesting facts. We have already spoken of helium as the offspring of radium, but here the analogy is not perfect, for these helium atoms are given off also by uranium on its own account, and after radium has given birth to the emanation, we find this descendant giving forth the same helium atoms also. Indeed we find that these alpha particles, or helium atoms, are being produced at no less than seven stages in the genealogic tree.

If we desire to consider the subject in detail we find that uranium is not the direct parent of radium, there being two stages between uranium and radium, so that the former is really the great-grandparent of the latter. Radium is followed directly by the emanation, and that again by at least eight other stages. The pioneer investigators are inclined to think that the ultimate product will turn out to be the well-known element *lead*.

If the uranium atoms are breaking down and forming both radium atoms and helium atoms, it stands to reason that each of these atoms must be lighter than the uranium atom. The atomic weight of uranium is 238, while that of radium is 225, and that of helium only 4. In the same way we should expect the products of radium to be of less atomic weight than

radium. Therefore if lead is a possible product it must be lighter than radium, and so it is; radium's atomic weight being 225, and that of lead 207.

Without going into further detail, it must be quite evident that some of the elements are going to pieces, each product being "more beautifully less" than its parent.

Consider where all the energy of radium comes from. One cannot get energy from nothing, although the perpetual-motion optimist is slow to realise this. I have heard people say that Nature will give more than she demands in return, and they have quoted the ordinary lever as a witness. But a moment's consideration should dispel any idea of stealing energy by means of a lever. It is true that a man may move a heavy stone with the aid of a lever, while he could not move it by applying all his energies directly to the stone. But a man may also carry a cart-load of coals to the top of a building by taking one hundredweight at a time, although he could not lift the ton of coals in one lot. Observe that the man with the lever has to move the free end of it through a great distance to produce a very small movement of the stone. The theory of the conservation of energy tells us that Nature will only deal on a strictly business-like basis. We must give her an equivalent for that which she gives us.

We have seen that radium is constantly radiating away an extraordinary amount of energy. Where does it obtain this seemingly endless store of energy? Most

assuredly it is self-contained, and our ideas of to-day, concerning the construction of the atom, indicate that it is the internal energy of the atom which is being drawn upon. The rapidly revolving electrons which compose the atom are being freed from their long abode; some electrons escaping free, while others congregate together to form atoms of lighter atomic weight.

While the idea that lead is the ultimate product of radium is merely hypothetical, the idea that helium is a product of radium has received the solid support of experimental proof. It will be of interest to see how this proof has been obtained.

One does not hear of helium except in connection with science; indeed we were not aware till recent times that it existed on this planet. More than a generation ago Sir Norman Lockyer was examining the extensive wireless message furnished in the spectroscope by the Sun when he came upon a spectral line which had not been deciphered. This spectral line which attracted his attention was near one of the sodium lines in the yellow section, and Sir Norman observed that this particular line did not belong to any known spectrum. Here was an element, in the Sun, not known on the Earth, so Lockyer christened the element *Helium*, from the Greek word *helios*, the sun. This new element was found in other stars also, and it is interesting to note that it is found only in the hottest stars. We should therefore expect helium to be a very light element, as we believe the lightest

elements to be the first in the order of evolution which occurs as the stars cool. Of course Lockyer could not tell its atomic weight as long as the element remained at so great a distance, but when it was found later to exist upon this planet its atomic weight was determined, and it was found to be the second lightest element known, the record being held by hydrogen.

Before the days of radium, Sir William Ramsay, of London, was examining the spectra of gases contained in a certain variety of pitchblende known as *clevite*, when he discovered the same spectral line which Sir Norman Lockyer had found in the Sun and stars some twenty-five years earlier. Helium was unearthed upon this planet and observed here for the first time in 1895. The discovery is a remarkable one, because the quantity of helium gas contained in pitchblende is so very, very minute. In a former chapter I remarked that one advantage of being able to produce spectra by means of an electrical discharge was that we could observe the spectral lines of very minute quantities of gas. This was the method which enabled Sir William Ramsay to detect helium.

After this discovery, physicists became familiar with the spectrum of helium, which shows five distinct lines well spread throughout the visible spectrum. It may be remarked that helium is a most independent element, for it will not enter into partnership with any other element; it is one of the few inert gases which defies all attempts at chemical combination. In addi-

tion to this, helium held a record of its own; until quite recently it resisted the chemists' efforts to liquefy it. The very lowest temperature obtainable, to which all other gases succumb, left helium defiant.

Our present interest in this refractory gas lies in the suggestion, made by Professor Rutherford and Mr. Soddy, that helium was a product of radio-activity. Its presence in pitchblende would seem to indicate this, but the subject is not left open to speculation. Sir William Ramsay and Mr. Soddy were investigating the spectrum of radium emanation, which was of a temporary character. After some days they observed a few bright lines appearing, and as those became more and more distinct they proclaimed themselves to be a wireless message from some atoms of helium. These atoms were not in the tube when it was sealed, and they could not pass through the glass, so that they must have been born in the tube. Undoubtedly, helium was a product of radium emanation; these pioneers had actually witnessed the birth of helium in their laboratory.

In the light of the foregoing discovery, we can understand how it is that helium is always to be found in radio-active substances. There is not the least doubt that real transmutations have taken place within pitchblende. Uranium atoms have broken down and formed radium atoms, while the radium atoms have become unstable and given place to helium atoms. I purposely omit the emanation atoms, as they have so short a life.

What would the alchemists of the Middle Ages say, if they could return to their old habitation to-day and learn that actual transmutations do take place in Nature? It is evident that the American swindlers who professed recently that they had transmuted silver into gold were not scientists. As Nature steps from one transmutation to another, it is always from the heavier to the lighter atom; the atomic weights of uranium, radium, and lead being respectively 238, 225, and 207. These charlatan alchemists claimed to have transmuted silver (107) into gold (197).

In considering the population of a country we have to take into account the birth-rate, the death-rate, and the average age. If we desire to take a census of radio-active elements we must go upon a similar plan. From the death-rate, or rate of disintegration, of uranium, we find that it has a very much longer life than radium; probably somewhere about sixteen million years. Hence uranium is much more plentiful than radium, but what the latter lacks in length of life it makes up for in activity. A shorter life, but a merry one. The same holds good of radium and its emanation. The latter has a very short life compared to that of radium, and it is much more radio-active than the radium from which it has been obtained.

It is quite evident that highly radio-active substances must be rare. The novelist of the future need not picture his hero becoming a millionaire through his finding a mine of radium, from which he can draw illimitable stores of energy. It is apparent that there

would not be much of the hero left to enjoy his impossible find, for we know that even very small quantities of radium will produce serious physiological effects upon the human body. The late Professor Curie is reported to have said that he would not enter a room with a kilogram—about two and a quarter pounds—of pure radium, because it would doubtless destroy his eyesight, burn all the skin off his body, and probably kill him.

We set out in this chapter with the analogy of a conjuror producing objects from some hidden store, and we agreed that sooner or later his stock must give out. We see that the same holds good of radium and other radio-active bodies, but that fact does not warrant us to say that the world itself is going to pieces. If we lost all the uranium, radium, and other well-known radio-active bodies, our planet would not be depleted by any means. The scientific world, however, began to search for radio-active properties in ordinary matter, for there was the possibility either that some of those radio-active elements might be distributed throughout Nature, or that ordinary matter might be radio-active of itself.

Water from the mineral springs at Bath was found to be radio-active. The air of caves and cellars was found to possess this new property of matter in quite an abnormal degree, and it has been shown that even the ordinary atmosphere is very slightly radio-active. A Cambridge scientist found that freshly fallen rain was radio-active, and his method of demonstrating this

was very simple. Taking some freshly fallen rain in a small platinum vessel, he evaporated the water very rapidly by heating it. When he tested this vessel, containing an invisible residue, he found that it would discharge an electroscope, and it was clear that this was due to some radio-active property which disappeared in a few hours. Ordinary tap water, or rain which had fallen some time previously, when treated in exactly the same way, showed no such signs of radio-activity, although air bubbled through some tap waters has been found to be radio-active. Many of the ordinary metals, and also glass, have been found to possess radio-active properties. These facts seem to indicate that radio-activity is a universal property of matter, but this question cannot be definitely settled at present.

The man who embezzles money in very large sums is much more easily detected than the man who steals little by little over a long interval of time; the latter may, unfortunately, escape detection altogether.

We have seen that electrons are continuously expelled from red-hot wires, candle flames, and from all bodies in the act of burning. These electrons must, like the conjuror's productions, come from somewhere, but these electrons, no doubt, are some of the detachable ones forced away from their atoms.

It would appear that chemical reactions also give rise to a real dissociation of matter on a very small scale. Dr. Gustave Le Bon, of Belgium,

maintains that he has definitely proved this by experiment.

It is quite possible that all matter is radio-active, although we cannot detect the shortage ; indeed it does seem probable that the world is very, very gradually going to pieces.

CHAPTER XXIII

THE CAUSE OF RADIO-ACTIVITY

Atoms of unstable configurations—How to express the life of a quantity of radium—A change beyond our reach—The sensitiveness of the spectroscope—Where the internal energy of the atom came from originally

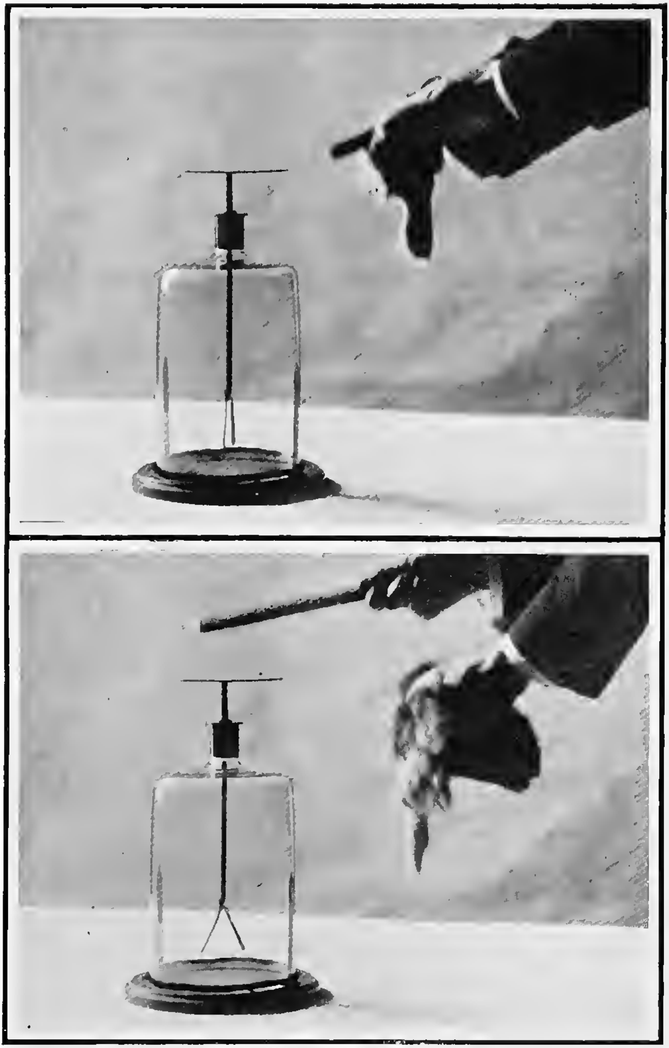
WHEN we were considering the construction of the atom, we saw how the electrons would form definite configurations according to the number of electrons contained in the atom. The illustrations forming the frontispiece assisted us in forming a definite mental picture of the atom.

Professor J. J. Thomson has shown that certain configurations would be unstable and would be liable to break down. The atoms of radio-active elements come under this category. If all the atoms composing a specimen of radium were to break down simultaneously there would be a sudden disappearance of the radium. But if only one atom in every ten thousand million breaks down in each second, the total disintegration will occupy some time. And as there are about one thousand million million million atoms in every gramme ($15\frac{1}{2}$ grains) of radium, it is evident that there is plenty of material available for a very long display. If we divide the total atoms by the

number disintegrating per second, we find that the gramme of radium should last about three thousand years. This is only a very rough way of expressing the facts, for, as the radium's volume decreases, it will not lose the same quantity each year. The more it disintegrates the more slowly will the remainder break down. It is because of this law that it is more convenient to say that radium will disintegrate half its atoms in about thirteen hundred years.

In accordance with the same law we find that although the emanation of radium takes a few weeks to completely break down, yet one-half of it has disappeared at the end of the first four days. Dealing with uranium in the same way, we say that half its quantity would disappear at the end of six hundred million years.

It is interesting to note that these various rates of decay, or disintegration, are constant and can neither be hastened or retarded by man. It would not be wise to be dogmatic and say that man will never be able to hasten the natural rate of disintegration of radio-active bodies. Who could have believed, a century ago, that we could ever get particles smaller than atoms to transmit enormous quantities of energy from place to place? And yet that is what really happens when we send electric power along a stationary wire. Who could have believed that we should ever get these invisible particles to carry our speech to distant towns, and to bring us immediate intelligence of what is happening in all parts of the civilised world?



THE ELECTROSCOPE IN USE

An insulated metal rod with two pieces of gold leaf attached to its lower end is protected by a glass jar. When any electrified body is brought near the metal disc attached to the upper end of the rod, the gold leaves become electrically charged and repel each other, as shown in the lower photograph. The presence of radium may be detected by an electroscope which has been charged previously, as explained in the text.

With regard to radio-active substances, all that we do say is that to-day we cannot affect the radio-active changes taking place in nature. We may heat the substance to the highest temperature possible, or subject it to the lowest temperature obtainable, but the same constant rate of change goes on.

The illustration facing page 228 helps us to appreciate a comparison between the delicacy of the chemical balance and the spectroscope. We marvel that the spectroscope can detect one-millionth part of a milligram of matter. What shall we say when we are told that the electroscope is a million times more sensitive than the spectroscope? (See illustration facing page 306.)

In an earlier chapter we tried to picture one four-millionth part of the lead which was rubbed off the pencil point when writing the single word shown in the illustration. And we found that the spectroscope could detect such an infinitesimal speck of matter. We learn now that even one millionth part of this already infinitely small quantity could be detected by the electroscope, if the matter was as radio-active as radium. Such divisions of a speck of an invisible speck of matter are far beyond our powers of imagination. What then shall we say of molecules, atoms, and electrons, contained within such an invisible speck?

With the chemical balance we detect matter by the pull which the Earth exerts upon it. With the spectroscope we detect matter by the æther waves which

its revolving electrons emit. With the electroscope we detect radio-active matter by its power to ionise the air and thus carry away the electric charge previously given to the instrument. But for this very delicate electric detector, we should never have been aware of the presence of some of the radio-active elements known to us to-day.

Undoubtedly, the cause of radio-activity is the disintegration of the atom. It is because the atoms are going to pieces, forming lighter atoms, and in so doing discharging electrons, that we get the well-known phenomena of radio-activity.

We know that the outward display of energy is due to the internal energy of the atom, but whence came that energy? The late Lord Kelvin said, in a letter already referred to, that the energy of radium was "no doubt due originally to the excessively high temperatures which have been and are being produced in the Universe." But does it not seem unnecessary to single out radium in this respect? There can be little doubt that the internal energy of all atoms has been derived originally from the temperatures prevailing while the electrons congregated together to form the atoms. Indeed stellar chemistry seems to indicate clearly that the lighter elements were formed first in the hottest stars, and that the heavier atoms only appeared at lower temperatures. We know that all the radio-active elements have the heaviest atoms known. I can imagine some one saying that this would suggest that the lightest atoms

will contain the greatest internal energy, but we must remember that the lightest atoms contain the fewest electrons.

It is true that we have no evidence of the internal energy contained in, say, an atom of iron, but that is because the energy is locked up within the atom and is suffering no apparent change such as we see in the radio-active atoms. It is only when there is a change or transformation that we can get any idea of the energy.

CHAPTER XXIV

WHAT IS GRAVITATION?

Newton's connection with gravitation—The anecdote of the falling apple—Newton's idea—The mathematics of his theory break down—A new measurement of the Earth alters matters—A great discovery—Interesting anecdotes concerning Newton and his calculations—Some medium is necessary for gravitation—Where the electrons may come in

WHILE the most exacting reader would not insist on every scientific subject being dealt with in a volume of this kind, some might be disappointed if no special notice were taken of such an important subject as the nature of gravitation.

The name of Sir Isaac Newton is so very intimately connected with the subject of gravitation that not a few people harbour the erroneous idea that Newton was the first to observe the force of gravitation; indeed that he discovered it. Needless to say, this is nonsense. Man could not fail to observe this force which is so prominent in our every-day life, and in Newton's time this force had its distinctive name, just as we have it to-day. Other philosophers had made an earnest study of gravitation before Newton's day, but it was Newton who discovered the laws of gravitation and applied them to the whole universe.

Previous to Newton others had suggested that the

Sun attracted the Earth and the other planets, but it was Newton who proved that the attractive power was the very same gravitational force which we see at work all around us on the surface of this planet.

I remember when a boy being one of the members of an informal debating society composed entirely of boys. At one meeting a member read an essay on "Newton's discovery of gravitation," in which the apple falling from the tree played a prominent part. When I learned later that Newton did not discover gravitation I naturally let the story of the apple go also. Indeed in quite recent years many authors treat this anecdote as mythical, but it is interesting to note that its truth is vouched for by no less an authority than Voltaire, who had the incident confirmed by Newton's niece, who had lived with the great scientist. Indeed the apple tree stood for a century and a half, and was known in the early years of the last century, when it was blown down in 1820.

To appreciate the anecdote of the falling apple we must remember that up till this time (1665) no one had ever connected the force attracting the planets to the Sun with the force known as gravitation. Gravitation was looked upon as a local force operating at the surface of the Earth. The idea that this force might extend out into space for millions of miles would have seemed highly absurd. Philosophers had provided the planets with ethers in which they might swim around the Sun.

Doubtless Newton had puzzled many times as to

the nature of the force which he had discovered to exist between the Sun and the planets. Very probably he was thinking of this problem when at the age of twenty-three he was sitting in his garden. An apple fell from a tree, but Newton had seen apples fall before. However, it suddenly occurred to him that it might be this very same force which attracted the moon to us and kept her falling round and round the Earth. He lost no time in calculating whether or not the force of gravitation could account for the pull of the Earth upon the moon. He was very sorely disappointed when his figures proved that this force was not sufficient to account for the amount of fall of the moon per second. Instead of working out to sixteen feet per second, the answer came out about fourteen feet per second. Newton was a great mathematician, his calculations were correct, so he had to dismiss the thought of gravitation being the force at work. Indeed he never mentioned his idea to any person at that time, but put his calculations aside.

Sixteen years later Newton returned to this subject, being convinced that his former idea must be correct. He also heard of a new and very exact measurement of the Earth having been obtained by Picard, of Paris, which proved that the Earth was considerably larger than all previous determinations had made it out to be. This would naturally alter Newton's former calculations. If the Earth were larger, the attractive force would be greater, the moon

would fall more feet per second. Newton lost no time in repeating his former calculations with this new data, and he very quickly saw that the figures were going to work out correctly this time. The full meaning of the discovery dawned on him; he was too excited to complete the calculations himself. His original theory had been right after all. This one man had discovered the Creator's plan in the universe; common gravitation governed the attraction of all the heavenly bodies. We cannot over-estimate the great importance of Newton's discovery.

Newton worked out all the mathematics of the subject so very fully that he left no problem for future generations except to discover the nature of the force. Two centuries and more have gone past and the problem is still unsolved.

There are many interesting anecdotes related by Newton's friends which go to show how his mind was absorbed by the mathematical problems connected with the subject of gravitation. He would rise in the morning, but before he was half-dressed he would begin his calculations and remain occupied in this way till well on in the day. He was quite oblivious of the fact that he was omitting to take his meals. There is a good story told by one of his friends, who called to see Newton one day when he was busy in his study. Dinner-time came but the great man still worked on in his study. At last the friend sat down and ate the dinner prepared for Newton, and when the great philosopher appeared some time later he

fatal objections to this idea also. However, we feel confident that the all-pervading æther is the medium, although no one can suggest the nature of the strain produced in it. We pull a stone away from the Earth and the two bodies react upon each other.

Before the days of the electron theory of matter, it was suggested that if matter were a rarefaction of the æther, there would be a stress of the æther towards such a partial vacuum. The stress between two such partial cavities would be least in the space between them, so that they would be forced towards one another. If the electrons should turn out to be rarefied æther, then this idea may be developed into a reasonable theory.

Suppose for a moment that we could imagine the revolving electrons producing a sort of æther vacuum within the atom. The more electrons the greater the vacuum, and therefore the greater would the stress be, impelling the masses of matter to move together. We require very sensitive apparatus to detect the attraction between any two pieces of matter; the Earth's attraction upon them is so immensely greater. Indeed, all gravitational force is very small; we only observe it because of the gigantic mass of the Earth. Electrical attraction is millions of times more energetic than gravitation. In the illustrations facing page 54, we see how much more powerful electrical attraction is than gravitation.

Whatever the nature of gravitation may turn out to be, there is abundant evidence that it is constant. It is

in no way affected by any alteration we can make in the conditions of atoms or their electrons. But then we cannot affect the main body of revolving electrons which compose the atom; they are constant. We may look forward, therefore, to a theory connecting these revolving electrons with the æther, producing a constant stress wherever matter exists. And although a century and a half has passed since Newton's great work was given to the world, we may still hope that the nature of gravitation will be discovered.

CHAPTER XXV

CONCLUSION

The studies of science—Complete change of ideas—Our great ignorance—An amusing conversation—Our position to-day—The electron's place in the universe

OUR scientific ideas of to-day are certainly very different from those of our grandfathers. In the foregoing chapters we have seen something of the immense stride which has been made during the last decade.

It is curious how very different we have found things to be from what our ancestors imagined them. They believed light and heat to be material things; we know definitely that these are merely modes of motion in the all-pervading æther. They believed the atoms of matter to be indestructible and eternal, but with the discovery of radio-activity, we have direct evidence that this is not the case. Not so long ago electricity was looked upon as a mode of motion—a form of energy—and now we know that it is a real existing thing, concerning whose particles we have gained a great deal of exact knowledge within the last few years. Just as we think the scientific ideas of our grandfathers to have been very crude and primitive, so may our ideas of to-day appear to some future generation.

We are quite conscious that there is a very great deal concerning which we know little or nothing. For instance, we have no idea of the nature of the æther, life, or positive electricity. And in the preceding chapter we saw that the long-standing problem of the nature of gravitation still remains unsolved. These are only a few examples of our ignorance. Fortunately we realise that we have much to learn.

The first step to knowledge is to know that we are ignorant.—CECIL.

When the great French savant, Arago, was asked by a distinguished lady a number of puzzling questions he modestly answered, "Madame, I do not know." It seemed strange to the lady that so learned a man should be so ignorant, and when she asked him how it was that he, who was in the forefront of science, did not know these things, he simply replied—"Madame, I do not know."

Occasionally we meet the man who knows everything. To his intimate friend he boasts that he always gives some answer to every question. Needless to say, that man does not possess a true scientific spirit. However, even this man is usually willing to acknowledge that he does not know what electricity is. A few years ago, when journeying by train, I overheard an amusing conversation between two fellow passengers. They had both been brought up in the country, but one had evidently some connection in the city with electrical work. His friend said—"Man, you don't

know what electricity is," and I was surprised to hear the accused say that he "did so." His explanation was that electricity was made of sulphuric acid and lead, from which statement it is evident that he had some acquaintance with accumulators.

Our true position to-day is this. We find invisible electrons at work all around us. These tiny particles of negative electricity form various configurations; these are the atoms of matter. The atom is a miniature solar system of revolving electrons. On the outskirts of this revolving system there are satellite electrons which set up waves in the surrounding æther of space; these waves we call light and heat.

Then there are detachable electrons which can pass from one atom to another. A steady locomotion of such electrons along a wire constitutes a continuous electric current, while a surging to and fro of these electrons is described as an alternating electric current. If the to-and-fro motion is rapid enough these electrons set up those "wireless" waves in the æther by which we send intelligence to and from ships far out at sea.

A sudden expulsion of those detachable electrons from one body to another constitutes an electric discharge. These electrons are shot off like bullets from the one object to the other.

We see how a discharge of electrons from the Sun to the Earth causes auroræ, provides nuclei for the formation of clouds in the upper atmosphere,

and accounts for atmospheric electricity with its occasional displays of lightning.

We see that owing to an accumulation of these electrons the Earth has become a negatively charged body.

We see how the steady motion of electrons (an electric current) produces a certain disturbance in the surrounding æther; this we describe as a magnetic field. We account for the Earth's magnetism by a flow of electrons within the Earth's crust; the motion being due to a temperature gradient.

We see some atoms giving up one or more detachable electrons which are accepted by other atoms, producing a disturbance in their electric balance, and causing the atoms to attract one another and become chemically united. In this way we account for the production of all the variety of compound substances known.

We find that electrons, from whatever source they are obtained, are always identical.

Referring to this electron theory, the Right Hon. A. J. Balfour, when president of the British Association, said—

"All will, I think, admit that so bold an attempt to unify physical nature, excites feelings of the most acute intellectual gratification. The satisfaction it gives is almost æsthetic in its intensity and quality. We feel the same sort of pleasurable shock as when from the crest of some melancholy pass we first see

far below us the sudden glories of plain, river, and mountain."

We see that there is a complete evolution from electrons to atoms and molecules and through radio-activity back to electrons. We have seen that in this universal evolution, the evolution of man has occupied a very small part of the vast time required for the change from not-living to living matter. The atoms forming our bodies have been in existence since the foundations of the world were laid, and when *we* have left this planet *they* will persist in some other forms—

> "Imperious Cæsar, dead, and turned to clay,
> Might stop a hole to keep the wind away."

Science only deals with the physical and material. Conclusions such as that just quoted from Shakespeare's *Hamlet* relate only to the material side of man. True Science does not seek to deprive man of his soul, or to drive the Creator from his Universe, but it honestly endeavours to study His marvellous works.

APPENDIX I

THE INGREDIENTS OF THE WORLD

THE following tables are based upon the particulars determined by the International Committee of 1906. The first table is arranged alphabetically, as is customary; in the second table I have arranged the elements according to their atomic weights; while the third table places the ingredients in the order of their discovery.

THE NAMES OF THE ELEMENTS (*alphabetically arranged*)

Aluminium	Fluorine
Antimony	Gadolinium
Argon	Gallium
Arsenic	Germanium
Barium	Glucinum (*alias* Beryllium)
Beryllium (*alias* Glucinum)	Gold
Bismuth	Helium
Boron	Hydrogen
Bromine	Indium
Cadmium	Iodine
Cæsium	Iridium
Calcium	Iron
Carbon	Krypton
Cerium	Lanthanum
Chlorine	Lead
Chromium	Lithium
Cobalt	Magnesium
Columbium (*alias* Niobium)	Manganese
Copper	Mercury
Erbium	Molybdenum

Neodymium	Silver
Neon	Sodium
Nickel	Strontium
Niobium (*alias* Columbium)	Sulphur
Nitrogen	Tantallum
Osmium	Tellurium
Oxygen	Terbium
Palladium	Thallium
Phosphorus	Thorium
Platinum	Thulium
Potassium	Tin
Praseodymium	Titanium
Radium	Tungsten
Rhodium	Uranium
Rubidium	Vanadium
Ruthenium	Xenon
Samarium	Ytterbium
Scandium	Yttrium
Selenium	Zinc
Silicon	Zirconium

It will be observed that the elements which we find occuring in radio-active changes—such as the emanation gas—are not included in this list, for they are known to us by their radio-active properties alone.

The Elements in Order of their Atomic Weights

Hydrogen	1.008	Magnesium	24.36
Helium	4.00	Aluminium	27.1
Lithium	7.03	Silicon	28.4
Glucinum	9.1	Phosphorus	31.0
Boron	11.0	Sulphur	32.06
Carbon	12.0	Chlorine	35.45
Nitrogen	14.04	Potassium	39.15
Oxygen	16.0	Argon	39.9
Fluorine	19.0	Calcium	40.1
Neon	20.0	Scandium	44.1
Sodium	23.05	Titanium	48.1

Vanadium	51.2	Iodine	126.85
Chromium	52.1	Tellurium	127.6
Manganese	55.0	Xenon	128.0
Iron	55.9	Calcium	132.9
Nickel	58.7	Barium	137.4
Cobalt	59.0	Lanthanum	138.9
Copper	63.6	Praseodymium	140.5
Zinc	65.4	Cerium	140.25
Gallium	70.0	Neodymium	143.6
Germanium	72.5	Samarium	150.0
Arsenic	75.0	Gadolinium	156.0
Selenium	79.2	Terbium	160.0
Bromine	79.96	Erbium	166.0
Krypton	81.8	Thulium	171.0
Rubidium	85.4	Ytterbium	173.0
Strontium	87.6	Tantalum	183.0
Yttrium	89.0	Tungsten	184.0
Zirconium	90.6	Osmium	191.0
Columbium	94.0	Iridium	193.0
Molybdenum	96.0	Platinum	194.8
Ruthenium	101.7	Gold	197.2
Rhodium	103.0	Mercury	200.0
Palladium	106.5	Thallium	204.1
Silver	107.93	Lead	206.9
Cadmium	112.4	Bismuth	208.5
Indium	114.0	Radium	225.0
Tin	119.0	Thorium	232.5
Antimony	120.2	Uranium	238.0

The atomic weights given here are not with hydrogen as unity, but with oxygen as 16; both systems are now commonly used, the latter having the advantage of bringing out more of the elements with whole numbers for their atomic weights. It will be observed that the three heaviest elements are highly radio-active.

Appendix

The Elements in Order of their Discovery

A.D.	Elements.	Discovered by
1450.	Antimony	Valentine (*German alchemist*).
1450.	Bismuth	Valentine ,,
1520.	Zinc	Paracelsus (*Swiss chemist*).
1694.	Arsenic	Schröder (*German*).
1733.	Cobalt	Brandt ,,
1738.	Phosphorus	Brandt ,,
1751.	Nickel	Cronstadt (*Russian*).
1766.	Hydrogen	Cavendish (*English*).
1772.	Nitrogen	Rutherford ,,
1774.	Manganese	Gahn (*Swedish*).
1774.	Oxygen	Priestley (*English*).
1780.	Uranium	Klaproth (*German*).
1781.	Tungsten	d'Elihujar (*Spanish*).
1782.	Molybdenum	Hjelm (*Swedish*).
1782.	Tellurium	Reichenstein (*German*).
1795.	Titanium	Klaproth ,,
1797.	Chromium	Vauquelin (*French*).
1801.	Tantalum	Hatchett (*English*).
1801.	Cerium	Berzelius and Hisinger (*Swedish*).
1801.	Vanadium	Del Rio (*Spanish*).
1803.	Osmium	Tennant (*English*).
1803.	Palladium	Wollaston ,,
1804.	Iridium	Tennant ,,
1804.	Rhodium	Wollaston ,,
1807.	Potassium	Davy ,,
1807.	Sodium	Davy ,,
1808.	Barium	Davy (*English*) and Berzelius (*Swedish*).
1808.	Strontium	Davy (*English*).
1808.	Boron	Davy (*English*) and Gay-Lussac (*French*).
1808.	Magnesium	Davy (*English*).
1808.	Calcium	Davy (*English*) and Berzelius (*Swedish*).
1810.	Chlorine	Davy (*English*).
1810.	Fluorine	Ampere (*French*).
1811.	Iodine	Courtois (*French*).
1817.	Selenium	Berzelius (*Swedish*).

THE ELEMENTS IN ORDER OF THEIR DISCOVERY—*continued*

A.D.	ELEMENTS.	DISCOVERED BY
1817.	Lithium	Arfvedson (*Swedish*).
1817.	Cadmium	Herman and Stromeyer (*German*).
1823.	Silicon	Berzelius (*Swedish*).
1824.	Zirconium	Berzelius "
1826.	Bromine	Balard (*French*).
1827.	Beryllium	Wöhler (*German*).
1828.	Aluminium	Wöhler "
1828.	Thorium	Berzelius (*Swedish*).
1828.	Yttrium	Wöhler (*German*).
1841.	Lanthanum	Mosander (*Swedish*).
1843.	Terbium	Mosander "
1843.	Erbium	Mosander "
1844.	Ruthenium	Claus (*German*).
1846.	Columbium	Rose (*English*).
1860.	Cæsium	Bunsen and Kirchloff (*German*).
1862.	Thallium	Crookes (*English*).
1863.	Indium	Reich and Richter (*German*).
1868.	Helium (in the Sun)	Lockyer (*English*).
1868.	Rubidium	Bunsen (*German*).
1875.	Gallium	Boisbaudran (*French*).
1878.	Ytterbium	Marignac "
1879.	Thulium	Cleve (*Swedish*).
1879.	Scandium	Nilson "
1879.	Samarium	Boisbaudran (*French*).
1885.	Praseodymium	Welsbach (*German*).
1885.	Neodymium	Welsbach "
1886.	Gadolinium	Marignac (*French*).
1886.	Germanium	Winkler (*German*).
1894.	Argon	Rayleigh and Ramsay (*English*).
1895.	Helium (on Earth)	Ramsay (*English*).
1897.	Krypton	Ramsay and Travers (*English*).
1898.	Xenon	Ramsay (*English*).
1898.	Neon	Ramsay and Travers (*English*).
1898.	Radium	Curie (*French*).

One is not surprised to find the commonest elements—such as iron, copper, gold, lead, and carbon—missing from the

foregoing list, as we have no record of the early discovery of these. From the curious names given to many of the elements one is quite prepared to find that these were discovered by foreigners. Of the six elements last discovered, no fewer than five of them have Sir William Ramsay's name attached to them, while the last of the list—Radium—is, as every one knows, a French discovery. Some may be surprised to find uranium appearing so early on the list. Although it was discovered in 1780, its radio-active properties were not observed till 1896.

APPENDIX II

HISTORICAL NOTE ON THE MODERN THEORY OF LIGHT

1804

For more than a hundred years man had believed light to be composed of material corpuscles, as suggested by Sir Isaac Newton towards the close of the seventeenth century. We can understand how difficult it was for those living in the opening years of the nineteenth century to accept the new idea put forward by Professor Thomas Young, of the Royal Institution (London). Dr. Young's idea was that light was merely a wave motion in the æther, and he set forth his theory in the *Bakerian Lecture* of 1804. The lecture was published in full in the *Philosophical Transactions* of that year.

I have referred already to the criticism which appeared in the *Edinburgh Review* of 1804 (vol. v. p. 97). There are seven pages of scathing criticism, the reading of which makes one wonder what the critic would say if he could return to this planet and see that Dr. Young was entirely right. For the sake of those who cannot refer conveniently to the old Journal itself, I make a few extracts.

After referring to past rebukes which the Journal had found it necessary to give Dr. Young, the critic says that this Bakerian Lecture "contains more fancies, more blunders, more unfounded hypothesis, more gratuitous fictions, . . . all from the fertile, yet fruitless, brain of the same eternal Dr. Young. . . . In our Second Number we exposed the absurdity of this writer's 'law of interference,' as it pleases him to call one of

the most incomprehensible suppositions that we remember to have met with in the history of human hypothesis. . . . But, in truth, Dr. Young is of a quick conception in hatching hypotheses. Whether it be, that those noxious things are naturally of rapid growth, like rank weeds, or that he is of a mind peculiarly 'nimble and forgetive.' . . . Dr. Young then proceeds to demolish, at one blow, the whole Newtonian theory of light, and to show, from Sir Isaac's own admeasurements, that his idea of particles moving in consequence of a projectile force is altogether absurd. This process of rapid demolition is somewhat curious; and we extract it as a specimen of his way." Then follows a long quotation from the lecture, the truth of every word of which is amply proved to-day, but the critic labels it "a metaphysical absurdity." He closes his review with the following words: "We now dismiss, for the present, the feeble lucubrations of this author, in which we have searched, without success, for some traces of learning, acuteness, and ingenuity, that might compensate his evident deficiency in the powers of solid thinking. . . . We came to the examination with no other prejudice than the very allowable prepossession against vague hypothesis by which all true lovers of science have for above a century and a half been swayed."

In the criticism, from which those extracts are made, there is an attempt to disprove Young's theory, but it is apparent throughout that the critic's real difficulty is that he fails to appreciate the reality of the æther.

It is of interest to note that wave theories had been suggested before Newton's time, but these were not in favour and were deliberately discarded by the great philosopher. Huygens' name is well known in connection with wave theories.

1815

Fresnel (France) did a great deal to advance the wave theory of light. Although he wrote to a friend on the 28th of December 1814 asking that some books might be sent to him

as he did not know the meaning of the phrase "the polarisation of light," yet by the end of the following year Fresnel was among the best authorities upon this subject.

1845

MICHAEL FARADAY—that "prince of experimenters"—when working in the Royal Institution (London), in 1845, was able to show a real connection between light and magnetism. He rotated a beam of polarised light by means of a powerful magnet.

1864

CLERK-MAXWELL (Cambridge) worked out the mathematics of the electro-magnetic theory of light, and proclaimed from his calculations that longer *electric* waves, of the same nature as light, must exist in the æther. These waves were not traced experimentally for about a quarter of a century.

1876

DR. JOHN KERR (Glasgow) succeeded in demonstrating that a beam of polarised light was affected by falling upon the polished pole of a powerful electro-magnet, when it was reflected therefrom.

1880

H. A. LORENTZ (Amsterdam) suggested that light was due to minute charged corpuscles revolving around the atoms of matter. He worked out the mathematics of this theory, but although many men tried to find experimental proof they failed at that time.

1888

HEINRICH HERTZ (Germany) detected and measured the electric waves prophesied by Clerk-Maxwell some twenty-four

years earlier. Hertz showed that these waves possessed the very same properties as light, but were of longer wave-length. This discovery made by Hertz completed the connection between electricity and light, and to-day no one will dispute the truth of the electro-magnetic theory of light.

1896

Professor ZEEMAN (Holland) produced experimental proof of Lorentz's theory. He showed that the revolving electrons were influenced by a powerful magnetic field, their speeds of revolution being altered, as explained at page 240.

APPENDIX III

PARTICULARS OF ÆTHER WAVES

ÆTHER waves are all of the same nature; they differ in wave-length. In the visible spectrum we have the following variety:—

Waves producing	the	sensation	of	RED	about	34,000	waves	to the	inch.
,,	,,	,,	,,	ORANGE	,,	37,000	,,	,,	,,
,,	,,	,,	,,	YELLOW	,,	42,000	,,	,,	,,
,,	,,	,,	,,	GREEN	,,	48,000	,,	,,	,,
,,	,,	,,	,,	BLUE	,,	51,000	,,	,,	,,
,,	,,	,,	,,	INDIGO	,,	61,000	,,	,,	,,
,,	,,	,,	,,	VIOLET[1]	,,	64,000	,,	,,	,,

As the speed of travel of all these waves is 186,000 miles per second, the number of waves passing any point in one second will be:—

Waves producing	the	sensation	of	RED	about	400	billion	per	second.
,,	,,	,,	,,	ORANGE	,,	440	,,	,,	,,
,,	,,	,,	,,	YELLOW	,,	500	,,	,,	,,
,,	,,	,,	,,	GREEN	,,	570	,,	,,	,,
,,	,,	,,	,,	BLUE	,,	600	,,	,,	,,
,,	,,	,,	,,	INDIGO	,,	700	,,	,,	,,
,,	,,	,,	,,	VIOLET	,,	750	,,	,,	,,

These figures also give us the rates of revolution which the electrons perform around their atoms to produce those æther waves.

From the following diagram we see that those vision-

[1] It will be clearly understood that between the extreme red and the extreme violet ends of the spectrum there exists every variety of wave-length—from one thirty-two-thousandth to one sixty-four-thousandth of an inch.

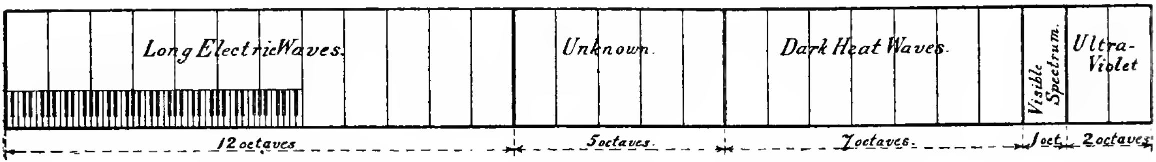


FIG. *E*

The range of Æther Waves

This diagram helps one to realise what a very small proportion of æther waves affects our vision. In the left-hand corner we see the range of an ordinary piano keyboard of seven octaves. We picture a long keyboard of twenty-seven octaves to represent the range of æther waves. The relative positions of electric waves, heat radiations, visible light, and ultra-violet light are shown, and additional particulars are given in the text.

producing waves only occupy a very small portion of the total range of æther waves. Here we have the idea of a very long piano-keyboard comprising twenty-seven octaves. The lowest note or rate of vibration shown here is about 50 million vibrations per second, but we know that much longer waves occur in some systems of wireless telegraphy. At the extreme right of the keyboard we have the highest note or rate of vibration, which is about 3000 billion vibrations per second, and this is the most rapid rate of vibration of which we have any knowledge.

APPENDIX IV

COUNTING THE INVISIBLE ELECTRONS

SOME readers may desire to know something more of the methods adopted in counting the electrons and in estimating their velocities, and yet they may not care to go into the matter as fully as the text-books do. In chapter iii. we were content to deal with general statements, leaving the details to be filled in by those who should choose to do so from the particulars given here.

We saw that it was only natural to suppose that the electrons were negatively electrified particles because they were shot off or repelled by the cathode or negative electrode. This point can be put to the test. If we place a small metal vessel within the vacuum tube so that the cathode particles or electrons will enter it, we can test the kind of electrification, and more than that—we can measure the amount of charge received from a given cathode stream in a given time. Our chief interest lies in the counting of the invisible electrons, which would seem an utterly impossible task. We know that this seeming impossibility has been accomplished.

It will be of interest to commence with Aitken's experiments in counting the invisible dust-particles contained in the air, as the method employed by him for that purpose was a stepping-stone towards this later remarkable achievement of counting the electrons.

Aitken pointed out that his experiments were based upon the fact that water vapour would condense upon the invisible dust-particles in the atmosphere, whereas it would not condense upon dust-free air. He carefully filtered all the dust

out of a volume of air by passing it through plugs of glass wool. Taking a glass globe filled with the dust-free air, and a similar globe filled with ordinary air, he admitted a little steam into both vessels. A cloud formed immediately in the globe containing the ordinary air, while no cloud or fog was produced in the dust-free air.

Before the steam was admitted one could not see any difference between the contents of the two vessels; they were both filled with invisible air. That there was a real difference became most apparent whenever the steam was admitted. The water vapour condensed upon the invisible dust-particles in the vessel containing the ordinary air and remained suspended in the form of a cloud. While the second vessel, which contained no dust-particles to act as nuclei, remained clear, the water condensing on the walls of the vessel. This is what would happen in our every-day life but for the presence of minute particles in the atmosphere; we should have no rain, but the walls of our houses and every other object would be wet.

Aitken found that, by varying the quantities of dust particles in the air contained in the glass globes, he could imitate a London fog, a Scotch mist, or a shower of rain. If there was a great quantity of dust particles in the air, then the water vapour in condensing would divide itself over the whole of these, and each particle having only a little water vapour attached to it could still float in the air, and in this way they formed a regular fog. Dense fogs are therefore most plentiful in large cities.

It was found also by experiment that a smaller quantity of dust in the air meant that each dust particle laid hold of a larger amount of water vapour, and in this way a Scotch mist was produced. In this case the dust particles were more heavily laden with moisture than the fog-particles were, but even those heavier mist-particles are able to float for some little time. Further experiments proved that if the dust-particles present were still fewer and if there was much moisture in the

air, a visible drop of water was formed around each dust-particle, and these over-burdened particles fell in the form of a shower of rain.

It occurred to Aitken that if he could only count the rain-drops he could tell how many dust-particles there were in the air. This he was able to do by causing the tiny rain-drops formed in a cubic centimetre of air to fall on a small silvered mirror. The mirror was divided into a large number of equal parts, and the number of rain-drops contained in one of these tiny squares was counted with the aid of a powerful magnifying glass.

C. T. R. Wilson found by experiment that if perfectly dust-free air, contained in a glass vessel, be ionised,[1] water vapour will condense and form a cloud. But we cannot hope to see the individual drops of water as Aitken did with difficulty upon his much larger dust-particles. First of all let us see how the cloud is produced.

In some of Aitken's experiments he adopted the following method of causing condensation upon dust-particles. An air-pump was connected to the glass vessel containing the air to be tested, also some water vapour. One stroke of the air-pump withdrew some air and caused the remaining air to expand suddenly. The expansion of the air caused its temperature to fall, and this in turn caused the water vapour to condense upon the dust-particles and form a visible cloud. This same method has been adopted in counting the electrons.

A glass globe containing some perfectly dust-free air and

[1] In preceding chapters we have considered several means of ionising the air. An electrical discharge, the passage of Röntgen rays, or the radiations from radium, will ionise the air. It will be remembered that the meaning of *ionising* is that the positive and negative atoms composing the molecules of gases become separated, and give us positive and negative *ions* or wanderers. Even the splash of water may cause some of the molecules in the surrounding air to split up into positive and negative ions; these have been detected at the base of waterfalls. A burning lamp and a red-hot metal wire produce ions in greater quantities.

some water vapour is subjected to X-rays, whereupon the air is ionised. There is no visible effect produced until some of the air is suddenly withdrawn by an air-pump attached to the globe. Thereupon a visible cloud is formed.

Long before the Cambridge physicists ever thought of counting electrons, Sir George Stokes had shown how it was possible to calculate the size of rain-drops in a cloud by observing the rate at which the cloud fell. The mathematical formulæ devised by Sir George Stokes came in very conveniently in these later experiments with clouds formed upon negative ions or atoms having a spare electron. The experimenter knew exactly how much water vapour would condense at each stroke of the air-pump. He therefore knew the total weight of water in the cloud, and by thus estimating the weight of each drop he could tell how many drops were in the cloud, and consequently how many ions having a detachable electron. This counting of the electrons was a most remarkable achievement, and with this data the mathematicians have been able to estimate the size and mass of an electron. Having previously determined the ratio of the electric charge of the electron to its mass, the value of the charge was now arrived at.

Another point of interest to the general reader will be the method of determining the velocity of the electrons. As mentioned in the text, this was determined by measuring the amount of deflection due to an electrostatic field, and that due to a magnetic field. The following diagram shows the method of measuring the electrostatic deflection. The electrons are shot off from the cathode C, and after passing through the slots in the partitions P the beam of electrons goes straight to the end of the tube, causing a spot of phosphorescence to appear on the glass. When the plates E E are oppositely charged by being connected to a few cells of an accumulator, the beam is deflected. The plate which is negatively charged will repel the flying electrons, while the positively charged plate will attract them. Hence, if the upper plate be the negative one, the beam of electrons will be

This diagram represents the special vacuum tube arranged for deflecting the flying electrons. The stream of electrons is shot off from the cathode C, and passes through the slots in the anode P, which is connected to earth, so that it shields the large tube from the electric field existing between C and P. The stream of flying electrons passes in a straight line to the end of the tube, where it strikes the phosphorescent glass and produces a luminous spot. It will be observed that this stream passes between two metal plates E E. If these two plates are oppositely electrified by

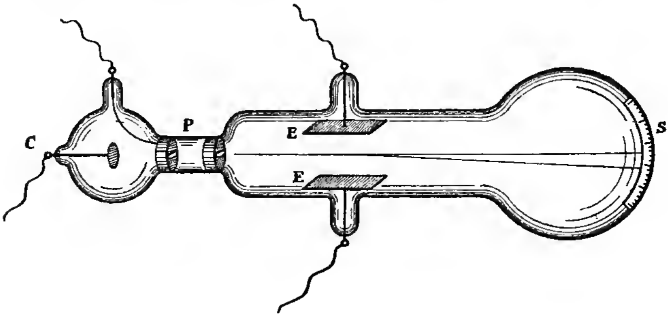


FIG. *F*

Experimenting with Electrons

being connected to a storage battery, the stream of electrons will be deflected from their straight path, and they will strike the glass at a different place. In the above diagram the upper plate is supposed to be negatively electrified, so that it repels the negative electrons, while the lower plate being positively electrified will attract them. In this way the stream of flying electrons is deflected downwards, and the luminous spot will appear at a lower point than it did originally. A paper scale is pasted on the outside of the tube at S, so that the amount of deflection may be noted. By means of this tube a great deal of interesting knowledge has been gained, as explained in the text.

deflected downwards, so that the luminous spot appears lower down on the end of the tube. A paper scale is pasted on the outside of the tube, so that the amount of deflection may be noted.

The same beam of electrons may be subjected to the influence of a magnetic field, by passing it between the lateral poles of a magnet. The one force may be so arranged that it neutralises the other, and by the two measurements thus obtained the velocity of the electrons is determined. The actual velocities of electrons are dealt with in the text (chapter iii.). This same apparatus provides the mathematicians with the ratio of the charge to the mass, mentioned on page 338.

A set of apparatus used in determining the foregoing particulars may be seen in the Science section of the Victoria and Albert Museum (London), to which Institution the apparatus has been lent by Professor J. J. Thomson.

INDEX

Index

Index

Index

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